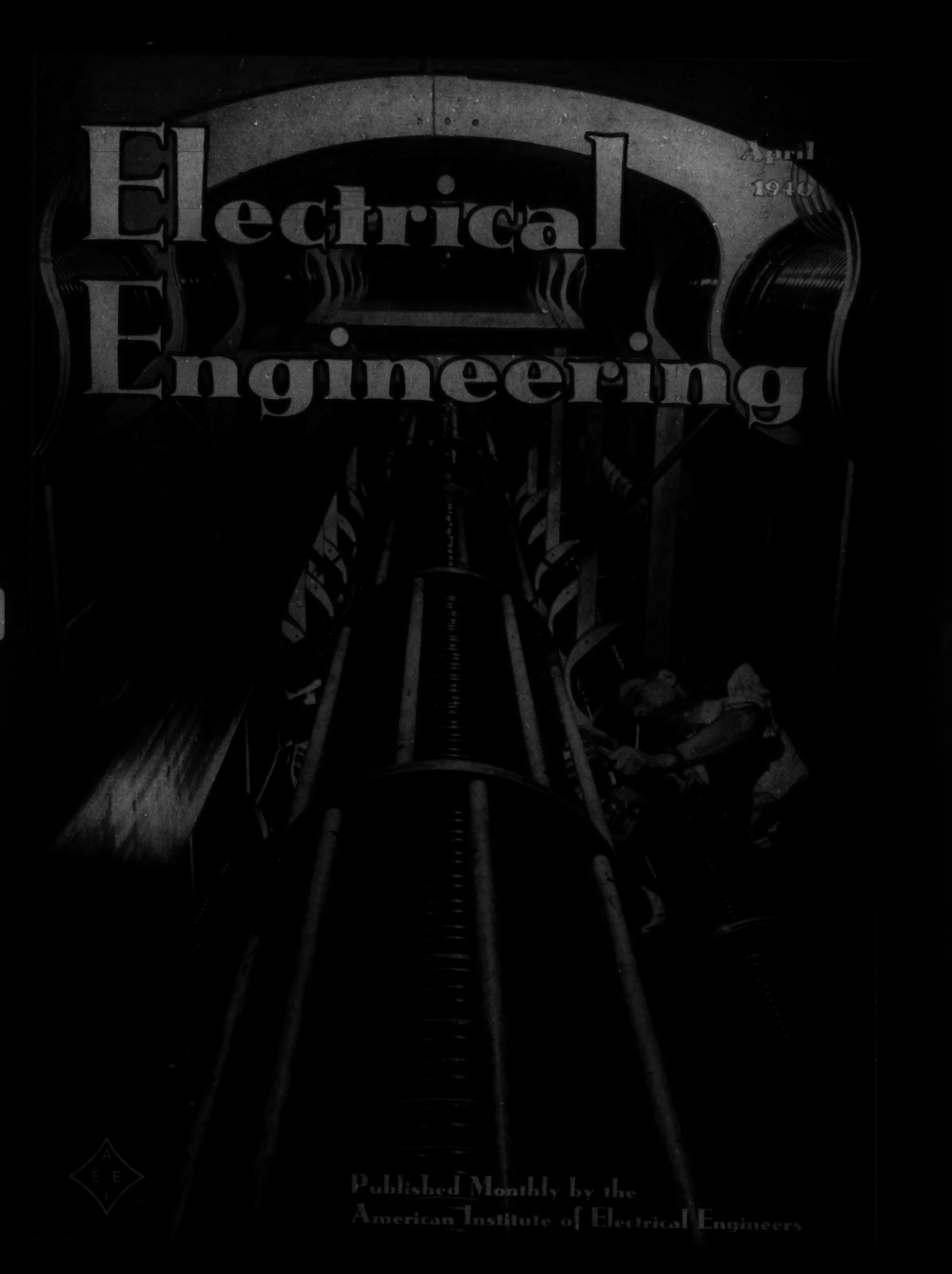
Electrical Engineering

April 1940



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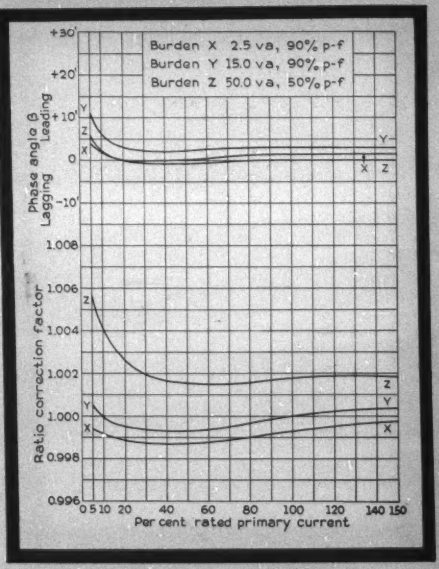

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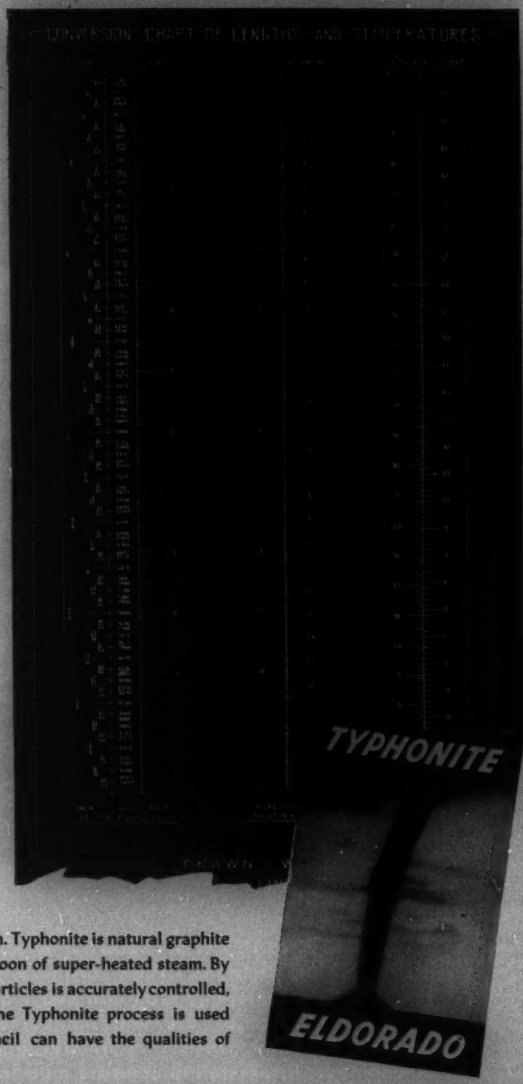

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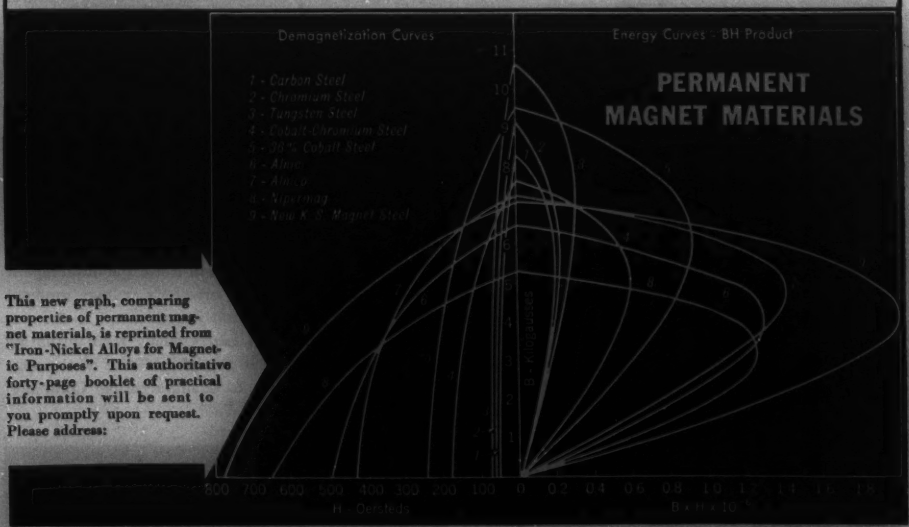

This new graph, comparing properties of permanent magnet materials, is reprinted from "Iron-Nickel Alloys for Magnetic Purposes". This authoritative forty-page booklet of practical information will be sent to you promptly upon request. Please address:

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After the stroke, laboratory tests proved the new arrester undamaged.

Fulchronograph, invented by Westinghouse engineers, recorded the stroke.

For the first time a lightning arrester has been proved by a measured natural stroke of lightning. Subject of the test was a new 3 kv Westinghouse porous-block Autovalve arrester, recently developed by Westinghouse engineers to withstand lightning of long duration.

21,000 amperes were safely discharged over a period of 20,000 microseconds and subsequent tests proved that the full force of the stroke caused no damage.

The remarkable increase in the new Westinghouse 3, 6 and 9 kv arresters' ability to handle severe lightning discharges of this type is due to two new basic design features . . . in the block and insulating compound. Laboratory research made it possible to increase the length of the block, per kv of rating, while still maintaining the low protective ratio, thus reducing the arrester's voltage gradient during discharge about 50 %. The second improvement is the new white insulating compound which has exceptionally high insulating qualities and reduces the possibility of partial flashover at the edge of the block. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pennsylvania.

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Electrical Engineering

Registered U. S. Patent Office

for April 1940—

The Cover: A view inside the "atom smasher" built at East Pittsburgh, Pa., by the Westinghouse Electric and Manufacturing Company and recently given its first public demonstration. The device is housed in a steel pear-shaped tank 30 feet in diameter and 40 feet high atop a small brick building.

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¶ Correspondence is invited on all controversial matters.

High Lights • •

Illumination at New York World's Fair. Scheduled for inclusion in the May issue is a comprehensive treatment of the nighttime illumination effects at the New York World's Fair, which opens its 1940 season May 11. Several four-color illustrations will be included as well as descriptions of the spectacular illumination effects achieved and many application diagrams and sketches showing how the various light sources are applied. The use of several new light sources previously found only in the laboratories will be described and illustrated.

Railroad Motive Power. Demands for higher scheduled speeds and for increasingly drastic operating economies have led to many recent developments in railroad motive power. The trends of these developments are traced in this issue by the electrical engineer of an eastern road who concludes: "It may be expected that advances will continue and that with further development in other railroad facilities the railroads will continue to serve as the country's most important transportation agency" (*pages 141–8*).

Urban Transportation. Statistics indicate some of the difficulties that would be involved in providing sufficient highways in the city of the future so that all passenger transportation might be by means of private automobiles. Through many developments the public transportation industry is endeavoring to meet the demand for improved urban transportation and to make this inherently more economical means of transportation more attractive (*pages 149–51*).

Letters to the Editor. Further consideration of membership participation in Institute elections and of currents and voltages of a three-phase unbalanced load, previously discussed in the "Letters" columns, and a comment on the new indirect luminaire for drafting-room illumination described in the February issue, pages 68–9, are included in this month's "Letters to the Editor" (*pages 166–8*).

Educational Trends. Data accumulated by the ECPD committee on engineering schools in the course of its accrediting program formed the source of a report on "Present Status and Trends of Engineering Education in the United States", prepared by Dugald C. Jackson (A'87, F'12) and published by the committee in 1939, from which the substance of the chapter on "Trends" is presented (*pages 152–6*).

Wave Shape. Mercury-arc rectifiers draw distorted currents from the a-c supply system, which in turn cause distortion in the voltage wave; reductions may be effected by increasing the number of phases. Telephone interference of one large installation was reduced by using phase-shifting transformers to increase the number of phases to 60 (*Transactions pages 218–26*).

Rectifiers. Rapidly expanding mechanization of coal mining has increased the need for readily movable underground substation equipment, for which the ignitor-type of mercury-arc rectifier is well adapted because it may be used advantageously at voltages as low as 275 volts (*Transactions pages 242–4*).

Voltage Regulation. Special designs of three- and four-winding transformers with synchronous condensers have been used to solve the problem of maintaining reasonably constant voltage levels in a large interconnected network having many load and generating points (*Transactions pages 212–17*).

Lightning Investigation. A co-operative investigation of the effect of lightning on transmission lines has produced data on the magnitude and distribution of current in tower members, overhead ground wires, conductors, and counterpoise wires; the average stroke current appeared to be 30,000 amperes (*Transactions pages 227–34*).

Arc-Furnace Loads. The violent fluctuations and low power factor of the load of electric arc furnaces may result in serious voltage flicker, especially if the load is served from a long transmission line; one particularly difficult problem was solved by installation of a synchronous condenser (*Transactions pages 234–42*).

Oscillograph Light Source. The intense brilliance of the capillary mercury lamps makes it a highly desirable light source for use with oscillographs and enables many records to be made on bromide paper, which is cheaper than film and easier to handle (*pages 157–9*).

Vibrator Inverter. A new type of vibrator inverter for supplying small a-c loads from low-voltage d-c sources opens the vibrating contacts only when the current through them is zero, thus obtaining minimum wear and freedom from spark interference (*Transactions pages 245–8*).

Television System. The Scophony system, which has set the pace for large-screen television in England, makes it possible to modulate a beam of light from an independent source and to project it directly onto a screen to form a large picture (*page 151*).

Radio Interference. Man-made radio noises may be reduced by application at the source of the appropriate one of the three basic methods of control: consideration in design, use of low-impedance shunt filters, or use of high-impedance series filters (*Transactions pages 193–201*).

Electrical Units. Some of the more important projects for securing greater uniformity in electrical units in international use are discussed, with the background of the proposed changes, by an author associated with the National Bureau of Standards (*pages 160–3*).

Circuit Breaker. A new air circuit breaker for 5,000-volt service extinguishes the arc by magnetically forcing it into an interleaving chute in which an ever-increasing cooling effect is encountered (*Transactions pages 202–12*).

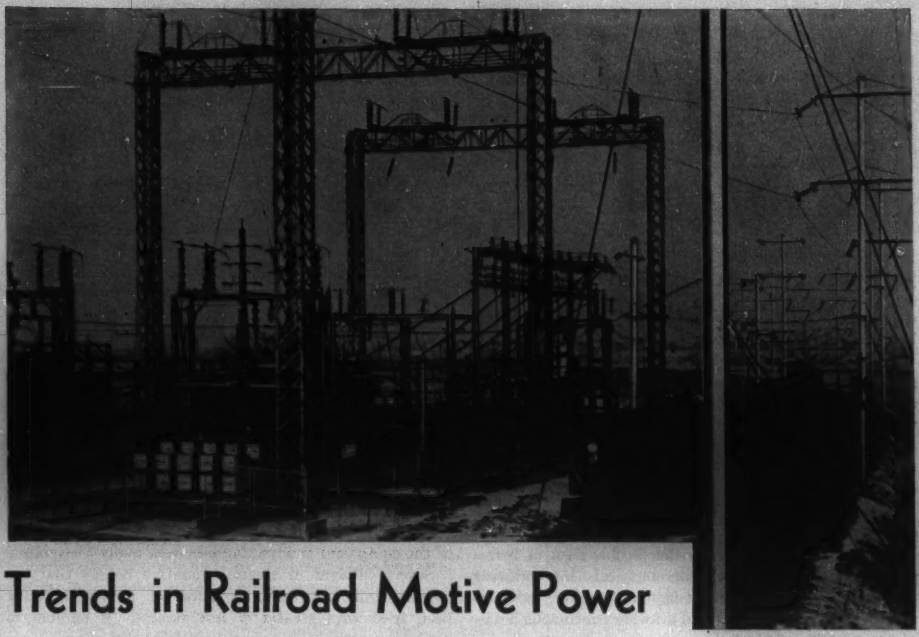
Well Drilling. Over-all performance of oil-well drilling rigs may be improved by the use of electrical rather than mechanical drive; the variable-voltage equipment is driven by an internal-combustion engine (*Transactions pages 248–56*).

Summer Convention. Appointment of the general committee for the 1940 summer convention, to be held at Swampscott, Mass., June 24–28, is announced with other preliminary plans in the Institute Activities section (*page 169*).

Turbine-Blade Research. An experimental high-pressure steam turbine enables engineers to "look" inside the turbine while it is running and observe the vibration of the blades directly (*page 159*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: An article on "this culture" in engineering by AIEE Past President J. C. Parker; an article discussing the question "Should engineers join a union?" by AIEE Presidential Nominee R. W. Sorensen; an article describing the new high-voltage laboratory of the United States Bureau of Standards by F. B. Silsbee (M'26); an article summarizing the results of a survey of noise in various types of rooms at different locations by D. F. Seacord (A'18); a paper on an unstable nonlinear circuit by C. M. Summers (A'30); a paper on the causes of corrosion of fine copper wires carrying a potential by H. N. Stephens and G. B. Gehrenbeck; a paper on load-rating theory for multichannel amplifiers by B. D. Holbrook (A'39) and J. T. Dixon (A'39); a paper describing some recent improvements in impulse voltage testing by C. M. Foust (M'31) and N. Rohats (A'36); a paper on protector tubes for power systems by H. A. Peterson (A'35), W. J. Rudge, Jr. (M'39), A. C. Monteith (A'25), and L. R. Ludwig (A'28); a paper on the theory and design of NEMA resistors for motor starting and speed control by G. C. Armstrong (A'39); and a paper on power supply for resistance-welding machines by the subcommittee on power supply for welding operations of the AIEE committee on electric welding.

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ Electrical Engineering is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). **Copyright 1940 by the American Institute of Electrical Engineers.** **Printed in the United States of America. Number of copies this issue 23,450.**



Trends in Railroad Motive Power

Growing demands for higher scheduled speeds and for increasingly drastic operating economies have stimulated many of the recent advances in railroad motive power

SIDNEY WITHINGTON
FELLOW AIEE

AMONG the important problems met in railroad operation today are those presented by the demand for increasingly high speeds in both passenger and freight operation. These involve increased power capacity and refinements in design, construction, and maintenance of locomotives. Braking is of especial importance in high-speed operation and is being developed to a noteworthy degree. Some of the problems may be visualized when it is considered that a train of a given weight has nearly three times the kinetic energy at 100 miles per hour that it has at 60 miles per hour. These items obviously involve added capital and operating expense, and railroad managements must decide carefully just where to draw the line in meeting the demands for speed—safety, of course, always being the primary and fundamental consideration. It may be said that, in general, speed limits are imposed by track and other fixed property rather than by motive-power limitations.

The light, modern train, though operating at increasingly higher speeds, often does not require the concentration of locomotive horsepower capacity that the long, heavy train of older cars requires. The motive-power problems are thus somewhat different as between these two classes of service, though there is no sharp dividing line, especially as horsepower may be advantageously used to attain not only high top speeds, but rapid acceleration—equally or more important in meeting schedules now demanded, particularly when runs are short and slowdowns frequent.

There are three main classifications in the railroad operating field which may apply under present conditions in discussions of developments in motive power: (1) main-line passenger service; (2) main-line freight service; (3) yard-switching and local freight service. In each of these three classes of service a number of developments have taken place during the past few years involving various forms of motive power.

Types of Locomotives

The demands of rail transport service have led to certain developments in various types of motive power. A comparison by a single quantity without qualification of the horsepower of locomotives of diverse types may be quite misleading, for the characteristics are rather fundamentally different among the various types. In a steam locomo-

Essential substance of AIEE paper number 40-29 presented at the AIEE winter convention, New York, N. Y., January 22, 1940.

SIDNEY WITHINGTON is electrical engineer, New York, New Haven and Hartford Railroad Company, New Haven, Conn.

tive, the horsepower rises with the speed and is maximum at only one point; above and below this speed the horsepower falls off. The Diesel locomotive, whether provided with mechanical or electric drive, is essentially a uniform-horsepower device. The engine operates at generally uniform speed and may supply power up to its full rated capacity, regardless of the locomotive speed, but with no overload capacity.

The horsepower rating of an electric locomotive may be a particularly vague quantity unless carefully defined. The limitation of the power of the traction motors is a temperature limitation. The inherent thermal capacity of the motors, however, allows the application of considerable overloads, depending upon the duration of the overload and on the design of the equipment. This overload characteristic, being inherent, is not obtained at a sacrifice of efficiency, weight, or cost. Horsepower ratings of electric locomotives are usually based upon continuous capacity, but overload characteristics often conform to the varying requirements met during a specific run, such as in starting, accelerating after slowdown, or in short grades, and the effective capacity actually available under such conditions is far in excess of the continuous rating.

There has been a great deal of discussion regarding the relative costs of various types of motive power. Such discussion, being based upon the flexible data of horsepower rating, is obviously quite empirical. An endeavor to correlate the more reliable figures, however, indicates roughly that, based upon rated drawbar continuous horsepower capacity, the relative weights per horsepower for road engines are: standard steam, including tender, 190–220 pounds; Diesel 150–160 pounds; and electric 100–120 pounds. The ratios of cost, also very approximately stated are: standard steam 100 per cent; electric 250 per cent; and Diesel 330 per cent. On account of the more generous short-time overload characteristics of electric equipment (as compared with steam or Diesel) which, as indicated, may satisfactorily match service requirements, the figure for electric locomotives as compared with steam may be materially reduced in specific instances. If, for instance, 90 per cent overload can be usefully employed for short periods in a given service, the figure of 250 per cent for the relative cost of electric locomotives would be reduced to the order perhaps of 130 per cent and the weight per horsepower to perhaps 55–65 pounds. The various other types of locomotives, which are generally somewhat experimental, cannot be considered in a comparison even as rough and approximate as this. It is quite possible that the practice of manufacturing Diesel locomotives for stock from standard designs may become common, reducing materially the cost through quantity production. Indeed this has been done to a slight extent with Diesel switchers.

Steam Motive Power

The conventional or standard type of steam locomotive has been subject to many important improvements in recent years, while still retaining its fundamental arrangement (horizontal boiler, horizontal cylinders with connecting rods, and coupled drivers). Boiler pressures and superheat have been increased, feed-water heaters, mechanical stokers, and many other devices have been added (many of these taken from central-station practice) which have increased the locomotive efficiency and capacity and practicable length of locomotive runs to a noteworthy degree. The thermal efficiency is now roughly between seven and eight per cent under normal load conditions, though much less than this when load and speed conditions are not favorable, as is often the case, and also much less when the locomotive operation is not in skilled hands. Increasing weights of trains, demanding higher drawbar capacity, together with increasing speeds required of equipment, mean increased horsepower which calls for larger boilers and grate areas, and many other improvements.

One of the greatest increases in economy in the operation of steam locomotives lies in increasing the length of runs. Twenty-five years ago few steam locomotives ran more than 100 miles without being taken off and sent to the engine house for inspection, fire cleaning, boiler washing, etc., whereas now runs of 500 to 800 miles are not uncommon when service conditions permit, though occasional stops are necessary for fuel and water in spite of considerable increase in the size of tenders. The direct operating savings are large, and the added annual mileage of the equipment is advantageous from many viewpoints.

Several designs of steam-locomotive boilers that are radically different from the standard equipment have been tried with greater or less success. A number of extra-high-pressure units have been tried with pressures up to 1,700 pounds. Such arrangements may be of the double-pressure type, the high-pressure system being a closed cycle from which the heat is transferred to the secondary-pressure steam supplied to the cylinders which are usually of standard design. This arrangement has the advantage of reducing boiler-feed-water-treatment problems where high pressure is involved.

The so-called "Velox" boiler has been adapted experimentally for locomotives abroad, but has not yet been tried in the United States. This is a boiler utilizing combustion under pressure in a small space with consequent high rate of combustion and high velocity of gases and highly efficient heat exchange for the generation of steam. Capacities of 70,000 pounds per hour are said to be obtained with a single boiler of this type at very high efficiency.

Somewhat related to the development abroad of the Velox boiler are recent developments in gas turbines, also in the developmental stage, but with interesting possibilities. The gas turbine is of two types, the "explosion" or constant-volume type, and the continuous-combustion or constant-pressure type; a turbine of the latter type is being applied in Switzerland to a locomotive. The device includes a compressor which provides air for both combustion and cooling. This air enters the combustion chamber and cooling jackets at a pressure of 20 to 30 pounds. The products of combustion and the cooling air subsequently mix and enter the turbine together. The compressor, mounted on the shaft with the turbine, absorbs a large share of the power developed, but the effi-

ciency of the turbine is so high that the net efficiency of the set, deducting the power used by the compressor, is not unsatisfactory. This locomotive has a net drawbar capacity of 1,900 horsepower with electric transmission of the usual type.

A number of steam-turbine locomotives have been built, especially in Europe, both with mechanical drive and with electric drive. Turbine locomotives have an obvious advantage in that they avoid reciprocating parts, but where mechanical drive is employed they are faced with certain limitations, such as the fact that their efficiency is maximum at but one speed. Furthermore, since the turbine is not reversible, either gears, a separate turbine, or reversing blades on the main turbine are required for reversing. In spite of these limitations, however, a number of turbine locomotives, both condensing and noncondensing, are in satisfactory operation abroad with direct mechanical drives, and it is quite possible that they may be generally developed.

One of the most interesting recent steam locomotives is the high-pressure turboelectric locomotive designed for transcontinental use in the United States, described at length in the October 1939 issue of ELECTRICAL ENGINEERING (pages 407–13). The operating characteristics of this locomotive are in certain respects somewhat similar to those of the six-engine Diesel-electric locomotive referred to hereinafter, and comparisons will be exceedingly interesting and valuable after operating experience with both types has been accumulated.

Steam rail cars have been tried from time to time, both in the United States and abroad, but in spite of certain apparent advantages have never been applied in large numbers on account of various limitations. Cars for such service are now generally propelled by internal-combustion engines, as indicated later.

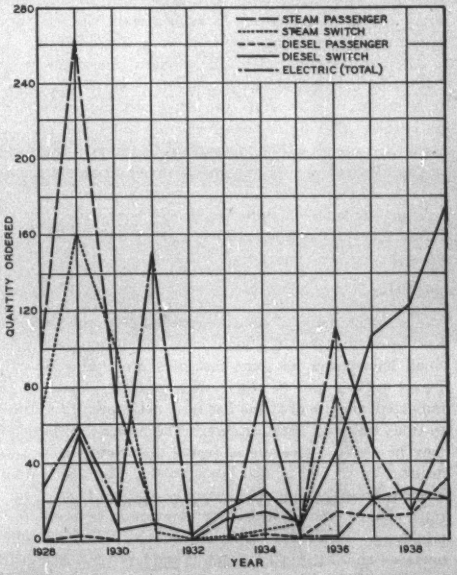
Diesel Motive Power

The Diesel engine has many obvious advantages in fuel efficiency and in operation, and has thus found considerable application in the railroad field, especially in handling relatively lightweight high-speed streamlined passenger trains on long runs through noncongested territory, and in yard switching and local freight-transfer operation.

The horsepower of the Diesel engine, as applied to rail service, is limited by considerations of practicable engine speed, right-of-way clearance requirements, and other factors. Engines now built have from 4 cylinders usually arranged vertically over the driving shaft, to 12 or 16 cylinders arranged either vertically or in "V" design. A novel 5-cylinder two-cycle engine with opposed cylinders has been developed with a capacity of 750 horsepower. Two pistons, vertically arranged in each cylinder, operate in opposite directions, a common combustion space serving both. Two crank shafts thus are employed, one above and the other beneath the cylinder, either geared or belt connected. This arrangement gives very satisfactory dynamic balance.

The two-stroke and four-stroke cycles are both largely used, and supercharging is common. The capacity of single prime-mover units normally varies from about 300 to 1,000 horsepower, though in some instances 1,200 or even 2,000 horsepower is used. When locomotives of larger capacity are required, two or more engines are employed, each usually driving its own generator, and all arranged for multiple-unit control. Engine speeds are usually limited to a maximum of about 1,200 rpm, though the speed most commonly employed with the larger engine units is about 750 rpm. The thermal efficiency of the Diesel engine is of the order of 25 or 30 per cent.

Electric drive in the United States is most common,



Number of locomotives of various types ordered by United States railroads, 1928–39. Separate curves are given for steam and Diesel switch and passenger locomotives, but the curve for electric locomotives includes both types

though elsewhere various forms of mechanical or hydraulic drive are also used, especially in capacities up to 400 or 500 horsepower.

HIGH-SPEED PASSENGER TRAINS

There is a tendency in the construction of modern cars toward increasing luxury by providing improved lighting, ventilation, air-conditioning, and other conveniences, which involves considerable auxiliary equipment. Recent installations indicate a tendency toward three-phase 220-volt, 60-cycle power for auxiliary service. This power, usually fed through the train from the train-service engine room at the head end, operates air-conditioning, lighting, battery-charging, ventilation blowers, refrigeration, radios, telephones, and, through suitable transformers, various

appliances. Even train heating is sometimes electric.

Traction-power requirements, as already indicated, are obviously increasing with the increased length and weight of trains. As has been said, the capacity of an individual Diesel engine thus far is limited by considerations of space and engine speed, so that when additional capacity is required, the solution of the problem lies in adding engine units. Thus a modern train of 11 cars weighing somewhat over 800 tons, is hauled by a locomotive containing as many as six Diesel engines, each rated at 900 or 1,000 horsepower, and each driving its own generator and traction motors. Such a locomotive comprises three cabs, each with two engine units, and is rated up to 6,000 primary engine horsepower. In such a train the auxiliary power may be quite separate from the main supply.

The capital involved in the modern streamline train hauled by a Diesel locomotive is relatively so large that it is necessary to operate the equipment as intensively as possible, making as many revenue miles per year as conditions permit. For this reason the trains of this type are usually assigned to long runs between terminals, sometimes more than 2,000 miles. Such operation requires certain maintenance en route, especially where the time at terminals of necessity is reduced to a minimum in the interest of high annual equipment mileage.

Rail Cars

The operation of single cars, especially on branch lines, has been mentioned. Such cars, requiring relatively small horsepower, in some instances are equipped with Diesel engines and in others with gasoline engines. As indicated, the use of steam has been attempted from time to time, but with little success. The power transmission may be electric, mechanical (using disk clutches), or hydraulic, up to 500 or 600 horsepower. The disk clutch has the disadvantage of interrupted torque during gear-ratio change, though this time element is reduced to a minimum, especially where a separate pneumatically operated and interlocked clutch is employed for each gear set. Hydraulic drive is employed to a large extent abroad, but is little used in the United States, although a form of simple turbine drive with centrifugal pump, successfully developed for highway coaches, may find application in rail cars. The latest development of this type now in use on railroads comprises a triple-stage turbine transmission. This type of drive is adapted for multiple-unit operation without complication and has an average efficiency of 80 per cent for all track speeds between 30 and 100 per cent of full speed.

In rail-car equipment the engine may be installed in a compartment in one end of the car or, more recently, in a horizontal position under the car body, or in the truck itself, thus leaving the entire car body free for revenue purposes. The location in the truck has the advantage of relieving the car body of vibration.

Yard-Switching and Freight Service

The development of Diesel motive power in freight and yard-switching service has been quite different in some respects from that for passenger service, though the same type of Diesel engines may be employed in both classes of locomotives. The railroads of the United States are concerned, as has been said, with the operation of heavier freight trains at higher speeds. This means a concentration of horsepower that would make Diesel locomotives quite out of the question for main-line through freight, on account of the capital expense required in the locomotive.

For flat-yard switching the Diesel-locomotive characteristics are so nearly ideal that they are being increasingly employed for such service. As has been said, the flexibility of the power transmission, whether electric or mechanical, permits use of practically full horsepower capacity at low speeds. A large part of the process of flat switching is carried on at low speed, and a Diesel locomotive of relatively low rated horsepower can thus compete favorably in speed of switching cars with a steam locomotive of considerably greater maximum rated horsepower capacity. Under some circumstances the cost differential between a steam switching locomotive and a Diesel of stock size capable of doing the same work may be negligible. All of the weight of the Diesel locomotive can be carried on the driving wheels, and it is not necessary constantly to accelerate a heavy tender in the reciprocating movements that constitute flat switching operations, though there is of course relatively less braking power without the tender. For these reasons and because of high thermal efficiency, high use-factor, and low stand-by losses during waiting periods, the use of Diesel locomotives in flat-yard switching is becoming common. It is probable that Diesel locomotives will find increasing use in switching service except under special conditions, such as locations in the vicinity of coal mines where coal is cheap.

Diesel switching locomotives are usually of capacities of 600 to 900 horsepower, and, more recently, 1,000 horsepower, usually in single-engine units, with electric power transmission between engine and driving wheels.

A development of interest has been a double-reduction gear for the driving motors. Such an arrangement obviously permits installing smaller traction motors operating at higher speeds to deliver equivalent horsepower at low locomotive speeds, than is possible with single-reduction gears, and there is thus some economy in first cost. The limitation in this type of drive lies in the relatively lower top speed of the locomotive as compared with one equipped with single-reduction gears. This is not of importance, however, unless the locomotive is expected to do some road work in connection with the yard switching or to make quick light moves.

While locomotives of 600 to 900 horsepower are eminently satisfactory for ordinary flat-yard switching, a switching locomotive may be required to haul a string of cars from one yard to another several miles away, perhaps stopping to pick up or drop cars en route. In service of this kind, 600 or even 900 horsepower may impose a serious speed restriction on the transfer trip, as compared with a top rating of perhaps 1,500 horsepower available from a steam locomotive with which otherwise the Diesel switcher might compare favorably. The limitations of the Diesel locomotive in this class of service may

(Above) A 900-horsepower Diesel-electric switcher in action in the Jersey City yards of the Erie Railroad

(Below) Two-unit 4,000-horsepower Diesel-electric locomotive of the Chicago and Northwestern's "400" passenger train

(Bottom) Wide-gauge (63 inches) 4,000-horsepower 3,000-volt d-c passenger locomotive recently built for the Paulista Railways, Brazil

(Top) Type GG1 4,600-horsepower 11,000-volt a-c passenger locomotive of the Pennsylvania Railroad

(Above) New York, New Haven and Hartford 3,600-horsepower 11,000-volt a-c passenger locomotive in action

(Below) A 10,600-horsepower locomotive in use on the St. Gotthard line of the Swiss Federal Railways

be offset, however, because of time saved which in steam-locomotive operation is necessary for turning the locomotive at terminals and for stops to take water. A few railroads have developed yard switchers of capacities of 1,800 to 2,000 horsepower for such service, though it sometimes may be economical to add an extra switcher for such an occasional transfer trip, since multiple-unit control makes unnecessary extra labor.

Some railroads have added storage batteries to the Diesel locomotive equipment in special instances, to supply short-time peak demands and permit relatively lower Diesel power to be installed for normal operation. This arrangement is also of advantage in operation within buildings where the Diesel exhaust would be troublesome.

By and large, it may be said that the Diesel locomotive is making a distinct success at the present time in passenger and freight yard switching because its characteristics are ideal for that class of service. It is also being successfully used in handling certain types of passenger trains, especially on long runs through noncongested territory where high sustained speed is possible. However, in spite of thermal efficiencies several times those of standard steam locomotives, it is not yet entirely established just how the combined cost of fuel, lubrication, repairs, capital charges, etc., will compare over a period of years with such charges for a steam locomotive of modern design hauling a train of the same weight. Since fuel costs vary widely in different localities, the Diesel locomotive may prove economical in one territory and expensive in another. Because of the relatively great length of a three-cab Diesel locomotive with auxiliary equipment, it may present a problem at stub-end terminals where the equipment may occupy a large part of the available terminal platform space.

Electric Motive Power

There is a tendency toward concentration of horsepower and increase of speed in electric locomotives, as with other forms of motive power. Developments in electric locomotives have been made possible by improvements in traction-motor design and construction and in various other details, both mechanical and electrical. There has been some tendency toward single locomotive units of larger capacity, and it is usually still contemplated that two or more units can be readily coupled together for added horsepower concentration and operated as a single multiple-unit locomotive by a single crew. The concentration of power may be thus relatively greater with electric locomotives than with any other class of equipment since, unlike other equipment, the power plant is not carried in the locomotive and the fuel and water are not hauled about with the train.

There has been a definite tendency, both in the United States and abroad, toward individual axle drive and away from coupling the drivers by means of side rods. The chief consideration in all such forms of transmission is the mounting of the motors on the truck frame, reducing to a minimum the unsprung weight on the axles themselves. The only side-rod locomotives recently produced for road service have been in Sweden and Hungary. Slip relays are now usually employed to protect the motors in the event of slipping of individual driving axles. In some cases, weight-shifting devices may be employed to transfer weight from idle axles to driving axles to increase the traction capacity where this may be required, as on grades or in starting.

The most common form of drive in use abroad is the link type, though this has never attained popularity in the United States. In this type of drive the motors are usually mounted above the driving axles and the power transmitted through pinions and gears, located usually outside the driving wheels. The links permit a variable distance between the pinion centers and driving wheels while maintaining torque conditions for driving. The location of the gears outside the driving wheels permits somewhat greater motor length.

The quill type of drive in various forms is common in the United States. In this type the motors are usually mounted above the driving axles, often in pairs, and the gears are generally located inside, between the driving wheels, mounted on quills which connect through springs with the driving wheels; in some cases rubber has been used with success. This quill spring type of drive limits the minimum size of the driving wheels on account of the necessity of maintaining sufficient room for the springs within the wheel centers. In some instances the quill springs are applied to the gears, rather than to the drivers.

An arrangement that has been applied successfully abroad, employs two motors facing each other above each driver with the armatures in line above the axle and parallel to it. Double-reduction driving gears to the axle are thus located between the two motors on the center line of the locomotive, each motor being equipped with a pinion which drives a jack-shaft which in turn operates a gear floating on the axle. The drive is accomplished through sliding blocks or universal couplings in the gear and on the axle, which transmit the torque while permitting the driving axle to follow the vertical spring play freely without affecting the peripheral speed of gears or driving-wheel rims. The drive unit is completely enclosed in oil.

In the United States twin motors have been very generally applied to electric road locomotives of recent years, two pinions thus driving a single gear. Nose-suspended motors in general have not been applied to locomotives of this type, although constituting a common arrangement in Diesel-electric and high-speed locomotives where the power per driving axle is limited.

In some types of locomotive the entire weight is carried on the driving axles, while in others a portion of the weight is on idling axles. The choice depends upon a combination of speed, power, and other considerations. At slow speeds satisfactory tracking may be obtained with all the drivers in one wheelbase without guiding trucks. Since this involves a minimum number of motors and no idle axles, it has the advantage of a minimum first cost. In other cases, as when the horsepower is great even though the maximum speed may be low, guiding or idling axles may not be needed for tracking purposes, but it may be found

economical to load the individual driving axles as much as possible, thus reducing the number of motors, and to carry the excess weight on idling axles. As speed and horsepower increase, tracking characteristics become paramount, and it has been found that best results are obtained by providing a reasonably light load per axle with four-wheel guiding trucks at either end of the locomotive, though some of the high-speed Diesel locomotives do not have guiding trucks. The most common electric-locomotive arrangement in the United States is two idling axles at either end of the cab, with the driving wheels, usually four or six in number, between on articulated trucks. Four driving axles also are not uncommon.

Locomotive frames are usually built up of steel parts, welded, though in the United States steel castings often still are employed. As with other types of locomotives, electric locomotives have been largely streamlined, or at least designed with rounded corners as a sort of compromise, or quasi streamlining. Since the locomotives are usually intended to haul standard coaches and are equipped for operation from either end, the effectiveness of streamlining is suggested rather than real.

In the design of traction motors there has been marked improvement during the past ten years, especially with single-phase motors. This improvement includes brush supports, increased number of poles, commutator design permitting increased peripheral speed, improved insulation, increased efficiency of ventilation, welded steel frames and housings, and numerous other details. Single-phase motors are also equipped with improved control, permitting application of higher voltages at the higher speeds; this produces an increase in horsepower at these higher speeds, a valuable characteristic in meeting the demands of modern railroading.

Forced ventilation is practically universally applied in road locomotives at the present time, and the insulation now used permits temperatures up to 140 degrees centigrade. Other forms of insulation are being developed, and there is little question that generally higher temperatures will be found practicable in the not distant future.

Electric apparatus on the locomotives is usually protected by circuit breakers, though in some instances the trolley-feeder breakers are relied upon for protection in case of trouble on the locomotive. In these cases no circuit breakers are installed on the locomotives, the protection being entirely from the line circuit breakers; in the event of trouble on the locomotive, after the power is cut off from the line, the pantograph is automatically lowered, thus clearing the line.

The motor voltage control on single-phase locomotives is usually effected by taps from the secondary coils of the main transformer, although in some instances abroad, the tap-changes are made on the primary or high-voltage side. Until a few years ago transformers in the United States were air-cooled, although oil-cooled transformers have long been standard in Europe. Recently oil-cooled transformers have been generally applied in the United States and in some instances inert-liquid cooling is used.

In almost all locomotives now constructed, two pantographs are applied per cab. In Europe both pantographs are normally operated together, while in the United States one is usually kept in reserve. Either single or double shoes are operated on locomotives and single shoes generally on multiple-unit cars and certain smaller locomotives. In the United States the pantographs are usually held against the wire by a spring and lowered by air, while abroad the reverse is true. Pantograph pressures vary a great deal. In Europe, pressures of 8 to 12 pounds are employed in single-phase electrification systems when the current collected is relatively small, while in d-c electrification systems of lower voltage and therefore higher current density, pressures may run as high as 26 pounds, which is a maximum. In the United States the pantograph pressure usually ranges between 26 and 35 pounds and does not seem to be a function of the amount of current to be collected.

The use of pantograph lubrication is gaining popularity, carbon often being inserted in recesses in the pantograph shoe, which in the United States may be either a steel stamping or steel with copper wearing strips screwed into it, and in Europe is usually aluminum or an aluminum alloy. It has been found that after the carbon has been applied for a short time the contact wire attains a glassy polish like that of a commutator, and the wear is considerably reduced, both on the contact wire and on the shoe itself.

Electric braking is used considerably abroad, but not very much in the United States, except in operation on long, heavy grades when regenerative braking is employed. Direct-current locomotives are readily adapted for regenerative braking by the addition of a relatively small amount of apparatus. The single-phase commutator motor is adapted to regeneration at line frequencies by means of excitation with alternating current at line frequency, though most of the electric braking on single-phase railroads is rheostatic rather than regenerative. This type of braking has been used to a considerable extent abroad as an auxiliary to the normal train brakes. The current generated may be either alternating (if the excitation is from the line), or direct, the motors being self-exciting. As is well known, the phase converter or straight three-phase equipment is automatically adapted to regenerative braking with little additional equipment, as it operates at speeds approaching synchronous speed regardless of load magnitude or direction.

In the United States train heating with electric locomotives is usually accomplished by means of oil-fired boilers in the locomotives or trailers. Electric boilers of various types are being experimentally tried. In Europe many trains are directly heated by electric heaters supplied from the locomotive bus.

Electrically operated air compressors are normally installed on electric locomotives. These are either single or in duplicate, depending on conditions. In Europe the electric air compressors are often supplemented by mechanical compressors operated from the axle of the locomotive, and the airbrake supply is thus independent of the integrity of power supply—an advantage especially on long descending grades.

Interesting developments have been undertaken abroad experimentally in utilizing power at commercial frequencies with single-phase distribution. This was first tried on a large scale in Hungary in about 1932 with 50-cycle power distribution and phase-converter locomotives, and the system is in successful operation at the present time. A single traction motor, supplied by a rotating phase-converter, drives the locomotives by means of side rods. On the most recently built locomotives in this electrification the phase-converter stator has two main windings, one single-phase connected to the line and the other polyphase connected to the traction motor. The stator windings are arranged to give either three-, four-, or six-phase supply. The rotor has four poles and the exciter and starting motor for the sets are mounted on the main shaft. Four fixed or synchronous locomotive speeds are obtained by combining pole changes on the traction motor with the different phase arrangements available from the converter. Intermediate speeds are obtained by variable resistances in the motor circuit.

Recently the German State Railways have undertaken experiments with similar power-distribution-frequency characteristics, supplying the contact system with power at 20,000 volts and 50 cycles. Various types of locomotives are experimentally operating, including: a phase-converter type with three-phase traction motors; mercury-arc rectifiers with standard series-wound d-c motors; and single-phase series commutator motors utilizing the 50-cycle supply direct.

The German experimental phase-converter locomotive carries four phase converters, each supplying a separate three-phase traction motor driving its own axle. The phase converters have wound rotors and stators, between which there is a free intermediate rotor with d-c excitation, which provides the rotating field necessary for phase conversion. During starting and when running at reduced speeds, the phase converters act as motors. There are three connections: In the first the converters and motors are in series, thus comprising eight traction motors; in the second the converters act alone as motors; and in the third the motors are fed from the stators of the converters. Intermediate speeds are obtained by variable resistance.

On the two rectifier locomotives the speed control is effected by varying the rectifier output voltage, in one case by means of tap-changing on the high-voltage transformer windings, and in the other by means of grid control of the ignition. Two sets of anodes are employed, supplied from separate transformer windings to provide voltage for series or parallel operation, depending on the position of the controller.

The series-commutator-motor locomotive carries eight motors designed for operation at 50 cycles. These motors have 14 poles and are mounted two per axle and controlled in the same manner as on the $16^{2}/_{3}$-cycle locomotives which are standard in Germany. Such motors are relatively heavy compared with motors for operation at lower frequencies, but this is offset by the saving in weight of transformers.

No data are available as to the relative operating advantages of these four types of motors, or indeed as to the 50-cycle distribution in this experimental project. It is to be hoped that information will be available in the not distant future.

A locomotive of high horsepower rating has been developed for operation especially on the St. Gotthard line of the Swiss Federal Railways, where grades of 2.7 per cent are involved. This consists of two cab units operating as a single locomotive. The wheel arrangement includes four driving axles in each half, or eight in all. The continuous rating of the 16 traction motors is 10,600 horsepower, the rating for one hour 12,000 horsepower, and 15,000 horsepower for 10 minutes. The weight of the two units complete is 513,000 pounds.

This unit has a double-reduction drive similar to that referred to hereinbefore, and the voltage control is on the high-voltage side of the transformer, consisting of plate-type contact taps arranged in a circle over which passes a motor-operated control arm, the entire mechanism being immersed in oil; 29 operating steps are provided. This locomotive is equipped for regenerative braking as well as carrying two compressors for supplying the braking system. Electric heat is provided for operation at 800 or 1,000 volts on circuits passing back through the train.

Recent locomotives having a wheel arrangement with six pairs of twin motors and a rated continuous horsepower of about 3,600 with short-time capacity of 7,600 horsepower, are in successful operation on the New Haven road. These locomotives are equipped to operate from either 11,000-volt single-phase trolley or 600-volt d-c third rail.

A type of locomotive that is operating satisfactorily on the Pennsylvania Railroad in passenger service at speeds up to 80 miles per hour and in freight service at speeds up to 50 miles per hour—either single or in multiple unit—has a similar wheel arrangement. The continuous horsepower rating of these units is about 4,600 and the short-time rating 8,500, nearly 90 per cent higher.

As has been indicated, the trend in electric-locomotive design is toward greater concentration of horsepower per locomotive unit, and by the multiple-unit operation to concentrate the horsepower available per train. There is a tendency to assign individual locomotives for either passenger or freight operation with obvious advantages, since the peak requirements in these two classes of service do not ordinarily occur at the same time.

Conclusion

Three general types of locomotives have been developed for railroad operation. Each type without question represents a good transportation tool and each has definite advantages. The developments applied in each type undoubtedly have been stimulated by improvements in other types, and each has thus been instrumental in helping the railroads meet the increasingly exacting demands made upon them for improvements in economy, efficiency, and service. It may be expected that advances will continue and that with further development in other railroad facilities the railroads will continue to serve as the country's most important transportation agency.

Getting Around in the City of the Future

ONE of the most important, and at the same time most controversial and least understood, problems of the modern city is that of improving its transportation or circulatory system. American cities have grown in area and in population at a rate that has far outstripped the facilities for handling the increased volume of local travel. In addition, development of the automobile has vastly increased the travel habits of everyone. But by jamming millions of automobiles into our existing street systems, we have made it increasingly inconvenient, costly, and dangerous to move about in urban areas.

Motivated by the general clamor and pressure to do something about urban street congestion, there is much hit-and-miss construction, dictated in too many instances by political pressure from groups who expect to benefit at the community's expense. There is also a strong tendency to assume that ultimately we shall all move about in private automobiles. Artists paint us beautiful pictures of the cities of the future, with their towering pinnacles and their skyways along which flow myriads of individual automobiles. Carried along by this attractive product of our imagination, we undertake huge outlays for street improvements which may or may not be wisely planned and which have a baffling way of becoming loaded beyond capacity almost as quickly as they are completed. In the meantime there is a tendency to ignore the vital public carriers and to overlook many opportunities for improving their facilities and service in carrying out community traffic-improvement plans.

CAPACITY OF CITY STREETS

If parking is prohibited, a typical city street with 60 feet of pavement width suitable for the movement of three lanes of traffic in each direction will have a capacity as indicated in table I. With automobiles alone moving on this street some 2,115 vehicles per hour represents its maximum capacity. This is based upon actual traffic checks made by competent engineers in surveys conducted under varying conditions. When public transit vehicles as well as automobiles move through the same street, the maximum number of vehicles per hour that can move satisfactorily drops to about 1,215. But the economic and social life of cities is not dependent upon the movement of vehicles; it is with the people in these vehicles that we are primarily concerned.

When we look at the capacity of our typical street in terms of the number of people served by the three alternative ways of using it, we get an entirely different picture of the situation. When used jointly by automobiles and street cars, this 60-foot street provides an artery for the movement of more than four times as many people as does the same street when used exclusively by private automobiles. This means that if we remove the street cars on such a street and devote its space entirely to use by automobiles, we shall require in addition to the old street, more than three new streets of the same width to have the same traffic capacity that we had before making the change—provided that we recognize, as we should recognize, that the proper measure of traffic capacity is in fact the number of people moved.

EFFECT OF WEAVING ON STREET CAPACITY

Carefully conducted studies have shown that the weaving of traffic from lane to lane on streets reduces efficiency markedly on wide arteries. Assuming the capacity of a single lane to be 100 per cent, if a second lane is added and traffic is not channelized by rigid enforcement, the additional space adds only 78 per cent to the capacity of the first lane. A third lane adds only 56 per cent, and a fourth only 26 per cent as much traffic capacity as that of the first lane. Thus, where weaving from lane to lane is not restricted four lanes will have a capacity of only 260 per cent; in other words, the effect of weaving is to reduce the capacity of 4 lanes in one direction to that of 2.6 lanes without weaving.

Table I. Vehicle and Passenger Capacity of a City Street

60-Foot Pavement—Three Lanes Each Direction—No Parking

	Vehicle Capacity		Passenger Capacity		
Types of Vehicles	Automobiles	Busses or Street Cars	Automobiles	Busses or Street Cars	Total
Automobiles only	2,115		3,700		3,700 All seated
Automobiles and busses	1,215	180	2,130	7,200	9,330 All seated
			2,130	9,000	11,130 Seated and standing
Automobiles and street cars	1,215	150	2,130	9,000	11,130 All seated
			2,130	13,500	15,630 Seated and standing

It is obvious then, that under congested conditions the way to get the maximum traffic capacity from a given artery is to confine the traffic to lanes or channels so as to avoid the losses engendered by weaving. The street car has been much maligned in modern traffic because it is rigidly confined to its lane by the rails upon which it operates. Assuming that we have available a rail car capable of holding its place in the traffic stream—which has been amply demonstrated with modern cars—the assumption that removal of rails in city streets in favor of free wheeled vehicles would increase the capacity of congested streets, is quite unjustified.

EFFECT OF SEPARATING GRADES AND INCREASED SPEED

To move more automobiles in congested areas it has been suggested that we need merely to build double-deck highways, to eliminate grade-crossing interference. Thus,

Excerpts from an address of the same title delivered at a meeting of the Engineers' Club of Baltimore, November 29, 1939, by Charles Gordon, managing director of the American Transit Association.

it has been assumed, we can provide our imaginary cities of the future with ample highway capacity so that workers and shoppers may drive themselves comfortably in swiftly moving streams of individual vehicles over skyways at various levels to and from their destinations in the lofty peaks that will pierce the sky in what are now congested business areas.

The available facts indicate some of the practical considerations with which we shall be confronted if we undertake to make these dream pictures come true. An ordinary city street four lanes wide, or with two lanes of automobile traffic moving in each direction subject to normal grade-crossing interference, has a conservative maximum capacity in each direction of 900 vehicles per lane per hour. When we build an elevated highway or a tunnel, we merely eliminate grade-crossing interference. Such crossing-free arteries have already been constructed to the point where we can accurately measure the increased capacity obtained. The Holland Tunnel under the Hudson River at New York, N. Y., serves as an excellent example. There careful traffic measurements have been made over a protracted period of time so that it has been well established that the maximum capacity of such an artery is approximately 1,500 vehicles per lane per hour, or 600 more than that of the conventional surface street.

Traffic will move at better speed on the grade-separated highway, and in that respect transportation is more satisfactory. But the capacity in number of vehicles per hour that can move past a given point, does not go up in proportion with the speed. Available data indicates a certain critical speed of about 30 miles per hour, at which the maximum number of vehicles move through a given artery in a given time.

CAPACITY OF LANES WITH VARIOUS VEHICLES

Returning now to consideration of capacity in terms of passengers rather than vehicles, table II gives a comparison of the relative capacities of various methods of moving people in congested areas. These figures give some interesting comparisons. Note particularly that the passenger capacity of a lane of busses on a surface street is about $3\frac{1}{2}$ times that of a lane of automobiles on an elevated highway. The capacity of a lane of street cars on a surface street is about 5 times that of a lane of automobiles on a skyway. If we also put the street cars in or on a grade separated structure to provide a direct comparison, their capacity becomes $7\frac{1}{2}$ times that of a corresponding lane of automobiles.

Table II. Capacity of a Single Lane of Various Types of Conveyances in Passengers Per Hour

Automobiles on surface streets	1,575
Automobiles on elevated highways	2,650
Busses on surface streets	9,000
Street cars on surface streets	13,500
Street cars in subway	20,000
Local subway trains	40,000
Express subway trains	60,000

We can now make a direct comparison of two alternative methods of building our cities of the future. Shall we provide subway trains for transporting our passengers or elevated highways for transporting them in private automobiles? Admittedly subways are expensive and beyond the resources of most cities until population and traffic densities can justify their cost. A four-track subway structure comprising two local and two express tracks costs from 6 to 18 million dollars a mile; but a subway of this type has a capacity of 100,000 passengers per hour in one direction on two of its tracks. It would require 21 four-lane elevated highways filled to maximum capacity with private automobiles to move 100,000 people per hour.

There is still another factor to be considered. Assume that we can build highways in our cities so that all workers and shoppers can transport themselves in their own automobiles, and that they can afford to do so. Before these people can function at the point to which they have been transported there must be space for the vehicles they leave. Authoritative statistics are available from which the requirements to be met can be readily determined. In central business buildings of modern type the floor area required per worker averages about 150 square feet. Corresponding studies of the space needed for the storage of automobiles in the most modern types of ramp or elevator garages indicate an average floor-area requirement of 240 square feet per automobile. Crediting each vehicle with the average loading in city traffic of 1.75 people per car gives a storage space requirement of 140 square feet of floor area per person. Thus the storage requirements for automobiles in the most modern types of garages average very closely per person transported the same as that occupied by workers in modern central-area business buildings. This comparison makes no allowance for the storage of cars by those who come into these districts to do business as shoppers and otherwise. Here then is the problem with which we are confronted if we are to approach the matter of improving the travel facilities in our cities on the assumption that everyone is ultimately to ride in individual automobiles.

With these facts in mind the transit industry today is fully conscious of its responsibility. The industry recognizes that it can win greater public use of its service and public co-operation in the appropriate allocation of street space to public and private vehicles only as it can demonstrate that it is alert and progressive. To that end remarkably rapid progress has been made during the past five years in the development of improved vehicles for urban transportation. The bus was originally a makeshift adaptation of a truck chassis. Today it stands as a full grown transportation vehicle in its own right. Crossbred between the bus and the electric car is the trackless trolley which has proved itself a very valuable and useful vehicle for urban transportation. When the size of vehicle required reaches 40-passenger capacity, and the service conditions require frequent stops, the trackless trolley adequately meets the problem of providing sufficient power by resort to the overhead trolley, while at the same time retaining to a considerable extent the maneuverability of the bus. Finally the street car itself has undergone a complete metamorphosis. Starting in the fall of 1929 and continuing to the present date, a research program supported by some 50 operating and manufacturing

companies in the transit industry resulted in the development of the so-called Electric Railway Presidents' Conference Committee car commonly referred to as the PCC car. Here again the public vehicle has thrown precedent to the winds and has pioneered a number of radical developments.

Thus through many developments the transit industry is trying to meet the demand for improved urban transportation. But this objective can be fully achieved only if the importance of public transit service in modern cities is recognized by leaders of public thought.

The part that any one mode or vehicle of urban transportation is to play in the future must be judged on the basis of its economic and social value to the community. The subject should be approached first of all as a civic matter. When plans for the improvement of a city's circulatory system are under consideration, the interests of any section, group, or business must be subordinated to the needs of the community as a whole.

The demonstrable economic advantage of collective transportation justifies the suggestion that through encouraging the development and greater utilization of such facilities a community may contribute most economically toward the improvement of modern traffic conditions. A much higher standard of convenience and comfort is needed if we are to achieve greater utilization of public facilities. That requires in turn the fullest co-operation between a community and its transit company.

Engineers in particular have a great opportunity and a great responsibility in the field of urban transportation. Not alone as engineers, but as citizens of their community they are in position to aid in the adoption of sound civic policies through their ability to understand the intricate problems involved. The future development of our cities will be influenced by psychological and political reactions as well as by economic and engineering considerations. Urban transportation problems will be worked out not alone in the drafting room and the laboratory, but in the arena of daily life where the public is the judge and where economic and engineering data may be outweighed by visionary schemes which appeal to the popular imagination.

Supersonic Light Control and Its Application to Television

THE principal element of the Scophony Laboratories (London, England) system of television is described in a recent paper.* The Scophony system, using entirely optical methods, has set the pace for large-screen television in England. The method employed can produce high-quality pictures up to 15 feet wide as well as 18- and 24-inch domestic pictures.

The author describes briefly the methods of television from the early days of the Nipkow disk to the present cathode-ray methods and then points out that the Scophony system of supersonic light control gives for the first time a practical means of storing picture signals at the reception end and brings to the receiver the advantages of electrical storage that the Iconoscope brought to the transmitter.

The basis of the Scophony method is the diffraction of light by supersonic waves in a liquid—a phenomenon demonstrated by Debye and Sears and shown by Jeffere as a possible basis for a light control of negligible inertia and power consumption and reasonable light efficiency. This type of light control makes it possible to modulate a beam of light from an independent light source and to project it directly onto a screen to form a large picture.

The construction and elements of the method of operation are best described in the words of the author. "The supersonic light control consists of a glass-sided cell filled with a transparent liquid, with a piezoelectric crystal having a natural frequency between 5 and 30 microseconds immersed in the liquid or inserted in one wall of the cell. The crystal is provided with electrodes on opposite faces, and these electrodes are fed by a high-frequency carrier, the frequency of which is approximately that of the crystal, and the amplitude of which may be modulated by the video signal received from the transmitter."

This arrangement causes the mechanical vibration of the crystal which is transferred to the liquid, thus forming a train of supersonic waves in the liquid through which light is passed. Since the supersonic wave length is small, diffraction spectra are produced proportional to the high-frequency carrier applied to the crystal. By stopping out the normal beam and using the light from the side images, an intensity proportional to the received video impulse appears on the screen.

The combination of this supersonic light control with cylindrical lenses as a means of increasing the amount of light that can be dealt with is the feature of the Scophony system that permits the production of large images. The practical form taken by the apparatus is described in an article titled "The Design and Development of Television Receivers Using the Scophony Optical Scanning System," by J. Sieger, pages 487–92 of the August 1939 *Proceedings* of the IRE. In the same issue, pages 492–6 appears an article "Synchronization of Scophony Television Receivers," by G. Wikkenhauser, giving data on the scanners of the Scophony system followed by H. W. Lee's article "Some Factors Involved in the Optical Design of a Modern Television Receiver Using Moving Scanners," pages 496–500. This last article discusses the optical efficiency and accuracy tolerances of the Scophony scanners.

*Abstracted from a paper "The Supersonic Light Control and Its Application to Television With Special Reference to the Scophony Television Receiver," by D. M. Robinson, published in the *Proceedings* of the Institute of Radio Engineers, volume 27, 1939, pages 483–6; abstract prepared under auspices of a special subcommittee of the AIEE committee on research (D. C. Jackson, Jr., chairman) by Ferdinand Hamburger, Jr. (A'26, M'32) instructor in electrical engineering, The Johns Hopkins University, Baltimore, Md.

Present Trends in Engineering Education

Increasing emphasis on research for undergraduates, widening recognition of the need for better pedagogical methods, and growing attention to the social relations of engineering are among desirable tendencies noted in a recent survey of engineering education

IS engineering education improving in its adaptation to its purposes, and are the observed defects being remedied? These two questions may be partially answered by tracing the trends in ideals and practices among the engineering schools. I will anticipate the ensuing statement of important trends by saying that the answer to each of these questions is a qualified affirmative. The situation is not wholly satisfactory respecting either feature, but the trends generally are good.

Two trends of great importance are the widely spreading recognition of the need for improved pedagogical methods with more responsibility placed on the individual students for self-education, associated with more sympathetic and wisely directed supervision, encouragement, and counsel from the staff, and the fuller acceptance, as a tenet, of the significance of research for the education of engineering students in the upper undergraduate years.

There goes along with these a generally increasing recognition among competent engineers that an engineering faculty of high intellectual and professional qualities usually attracts students of high order, whether the institution is of moderate financial circumstances and moderate facilities, or of great wealth and correspondingly great facilities. It is coming to be clearly seen by engineers that, to quote the Carnegie Foundation bulletin "The Student and His Knowledge," published in 1939,

> "The best part of education for youth is to come in contact with stirring personalities that have had great adventures with ideas. If a young mind can recognize what these ideas mean and whither they tend, it is undeniably the greatest possible stimulus for him to catch these meanings from a living person."

But it is well here to emphasize that for engineering students the phrase "contact with" must be understood as meaning "association with and working with, or under the intimate counsel of." Unhappily, this relation between the quality of students and the quality of the teaching staff is not always suitably recognized by administrative officers when making appointments or promotions.

The criteria applied to selecting and promoting staff appointees are in a badly mixed trend. In a few institutions notable effort is exercised to achieve a staff with the personal qualities recognized as important. In other institutions, there seem to be no such guiding principles, but other and less desirable criteria seem to be controlling. Data are not sufficient to prove that the trend has been one way or the other compared with the increasing aggregate number of staff members, but they do plainly show that the trend toward outstanding influence of some engineering schools (compared with others) has been coincident with increasing repute of their teachers in engineering thought, in contributions to engineering knowledge, and in encouraging their own close intellectual relations with ambitious and competent students.

With respect to students, it has come to be recognized in some degree that "the intelligent interest which the individual brings to bear upon a given subject" outweighs in importance for students of engineering the amount of time spent in formalized class exercises. The combination of this attitude and the practice of selecting more judiciously students to be accepted by the engineering schools seems to be raising the level of student achievement wherever the two ideas are joined in use.

The effect on student achievement that may be secured by student selection, carefully made and carefully maintained, is favorably commented on in "The Student and His Knowledge," which ascribes it to the fact that such selected minds "naturally tend to learn more than the curriculum requires; they are inclined to organize and to retain better than others what they learn." However, the existence of such trend-relations may be denied by many sincere administrative officers and staff members in engineering schools, and a fuller examination of such experience as now exists in the schools is necessary to give final proof to the point.

It is obvious that some engineering schools are directing increased care to the processes of selecting students (and particularly to selecting freshmen); and along with this, there is a growing attention to improving the study practices of the students, associated with encouragement to intellectual self-reliance. Financial aid for students is now being dispensed more steadfastly and judiciously with student selection in mind, whether the funds are provided through scholarships, student loans, or such other means as the plans of Stevens Institute and Yale University. Foremost quality of student achievement has gained the lead compared with quantity of mediocre achievement, and those who are often called the "superior" students receive more attention. It still apparently is difficult for faculties to take students at their individual levels and encourage them to progress at individual speeds, but some special devices, such as honor seminars in junior and senior years, show that the difficulty has begun to dissolve.

A slowly widening interest among the engineering schools in examinations of truly comprehensive character, and reduced emphasis on term examinations in individual subjects, is a trend which is now observable. Comprehensive examinations placed as qualifying examinations before promotion from the sophomore to the junior year have been discussed.

Digest of section VIII, "Present Trends in Engineering Education", of *Present Status and Trends of Engineering Education in the United States*, a report prepared by Doctor Dugald C. Jackson (A'87, F'12) for the committee on engineering schools of the Engineers' Council for Professional Development and recently published by the committee. The chart and table accompanying this article are adapted from material in section VI of the report.

Conventional and highly predigested textbooks continue in use in even the most dynamic branches of engineering, but stimulating treatises are not lacking for use. The latter are receiving increasing favor in institutions where teaching loads are not overheavy.

These things seem to go in association with the distinction of a faculty for its own achievements in science, engineering practice, and pedagogy; and reputation in those respects is tending to draw selected students to certain institutions for advanced study.

The increasing interest in student meetings of the national engineering societies (by districts or at general meetings) is a trend of notable importance which now has strong momentum. It proves a valuable aid to developing in the students a feeling of responsibility for their own self-education and (once established in this manner) this sense not only holds within college but also, happily, is maintained after graduation. Prizes offered for papers presented at such student meetings and other meetings of the societies are an effective part of the same active interest in the education of engineers that is now exhibited by the engineering societies. These meetings should afford an opportunity to emphasize the topics of engineering economy and of management, regarding which committees of the Society for Promotion of Engineering Education are doing such fine work.

One of the most encouraging features of the trends relating to student selection and improvement of study processes is arising in a few strongly entrenched engineering schools within which department border lines have been weakened. That is the tendency to carry on experiments in education and research in which more than one department takes an active interest. A somewhat analogous feature lies in the offering of experimental curricula that relate to developing aspects of engineering which have not yet been sufficiently mature to prove their ultimate stability.

SOCIAL RELATIONS AND RESPONSIBILITIES

A very impressive trend lies in the rather recently emphasized attention to the social relations of engineering and the social responsibilities of engineers. This trend is a very wide and fruitful affair which touches engineering education on all sides, from such monumental questions as the effect of engineering practice and invention upon private and public expenditures, to such administrative problems within the engineering schools as the proportion of admitted students who withdraw before graduation. One of the significant manifestations of this trend is to be observed in the interested co-operation now established between the national engineering societies, the Society for the Promotion of Engineering Education, and the numerous centers of engineering education. The Engineers' Council for Professional Development, with its four committees related to the education and professional recognition of engineers, is an outcome of this sympathetic co-operation between the societies and the instrumentalities of engineering education. The same influence of an expanding sense of social responsibility has favorably affected the co-operation between industry and the engineering schools, and between individual practicing engineers and the schools. In this, the engineering schools ought to develop a more thoughtful part, emphasizing pedagogical ideas.

This same broad question of social responsibilities involves the present high rate of broken student careers and also involves, in an administrative way, the organization of engineering schools. The woefully large proportion who enter the engineering schools as students but who withdraw for one reason or another before reaching the goal of graduation has been commented on again and again in conferences and reports, including the report of the SPEE board of investigation and co-ordination of 1923–29. A portion of the effort of such students is profitable to them but with many it is a plain waste of time and money. The ECPD committee on student selection and guidance hopes to discover measures for selecting the students who enter the engineering schools and also for providing some guidance for them so that the great waste may be lessened.

Into the broad field of social responsibilities for the institutions also comes the growth in popularity and in numbers of junior colleges. Their trend is forward and upward and many of them now include instruction in engineering subjects. The relation of such instruction to preparation for entering the engineering schools with scholastic credit is still in the stage of discussion.

TRENDS IN CURRICULA

Study of curricula reveals in some cases distinct trends and in others erratic variations. A dynamic three-quarters of a century, with vigorous growth of curricula amid clamoring expressions of needs, affords neither length of time nor calmness of spirit adequate to the clear outlining of principles and objectives for the educational processes in a great field of human endeavor where the field is open for free development. The results in engineering have been astonishingly good for the circumstances, as has been shown by the SPEE report of 1923–29. There has been in engineering education a long swing of changing proportions of subjects, changes of pedagogical methods, and formulation of specific curricula. The total trend has been and is one of steadily expanding accomplishment. Devoted and learned men have dedicated their lives to the achievement, often under discouraging circumstances. They have stirred large numbers to discipleship. Under the circumstances, the steadiness of the principal trends regarding curricula is notable; and this steadiness persists in the face of constantly applied examination of the educational situation.

The data show that the civil engineering curricula came to their highest concentration of technical subjects about 1915, and that the tendency since then has been a slight retreat. The same may be said of the curricula in electrical engineering. The mechanical-engineering curricula, however, came to their highest concentration of technical subjects somewhat later—about 1923. They have not shown the tendency to a retreat from this situation which is shown by the others, and at the present time exhibit a slightly stronger emphasis on technical subjects than the

data show for civil and electrical engineering. The trends in electrical-engineering curricula are shown in the accompanying chart. The great significance of these data, however, seems to be in the trends regarding time-allotments for arts of expression (spoken, written, and graphic), humanistic and social subjects, and free electives. The data show that English has substantially held its own (in hours assigned) over several decades, graphics have fallen off, and foreign languages have substantially disappeared, leaving a balance of freed hours. Economics and sociological subjects and free electives have taken up the freed hours. Shopwork may, here and there, have given up a few hours to the same cause.

This adjustment is worthy of the closest examination for the purpose of securing more hours for political economy and restoring some to foreign modern languages. An encouraging tendency of thought is observable in this field, but it is slight as yet and does not reach the heart of the situation.

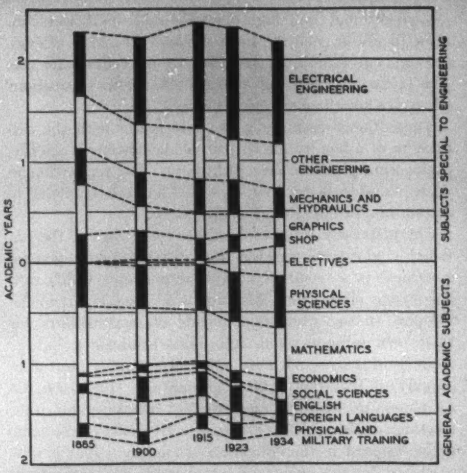
The change in attitude within the engineering schools toward instruction in English has been almost revolutionary. From a subject accepted as an item of the curriculum with only a degree of toleration, it has come to be esteemed alike by faculties and students (as well as by engineers in general) as an important feature in competent engineering curricula, but there is great need for resourceful originality applied to processes of teaching the subject. The work of the SPEE committee on English may do a great deal toward capitalizing on that situation. The conferences of that society on English instruction are having a good influence. At the same time, the foreign modern languages have lost support in the engineering schools, but an indication is appearing of some reversal of sentiment regarding them.

The trend in mathematics and the natural sciences has been strongly toward better grasp of the subjects by students. A part of this accomplishment arises from better-adapted teaching methods and another part from a better attitude toward research for students in the higher engineering classes.

Attitudes expressed within engineering circles toward the importance of economics and sociology (which here will be called jointly "political economy") as subjects for close and accurate study by engineering students have changed tremendously in the emphasis put on the words "importance," "close," and "accurate." But faculties have been slow in conceiving measures for accomplishing the purpose. It probably is a fact that engineering faculties now generally agree on a need to dovetail engineering into political economy in the curricula so that the two may directly and soundly influence each other, as has been done so well with engineering and the physical sciences, but the means for accomplishing this aim have not been set up. Many attacks on special aspects of the broad relations of the two are carried on with interest and apparent success, but no vigorous attack on the fundamental core of the joint problem has been provided as yet; and nowhere have funds been made available to support adequately such an attack.

The present tendency is for each institution to provide a considerable number of curricula, each possessing a large proportion of material that is substantially common to all, although the teaching methods and illustrations may be different, with each curriculum emphasizing the particular applications toward which it is directed. Thereby is obtained a freedom of choice among special fields needed to satisfy the legitimately diverse tastes of students, and also some freedom of choice among subjects by the provision of electives, while an integrally conceived but flexible plan is available for each student to follow. Some notably able engineering teachers preach an adverse doctrine, but the gradual increase in the number of soundly established and respected curricula shows the force of the trend. It is, however, becoming generally accepted that such curricula should be sufficiently similar during the first two years that students may readily transfer from one to another at the end of any term during that period.

A paramount problem, which needs to be settled before the dispute over length of curricula and the desirable extent and character of their diversity, lies in the definitions of the "fundamentals" of science and of political economy. Along with this goes the question of how much of each aspect of fundamental science and of fundamental economics and of fundamental sociology is needed in the composition of the common core in engineering curricula. Until these points can be decided, the trend of thought regarding variety and length of curricula will continue to be erratic because controlled by incomplete experimental empiricism. In our present situation, difficulties caused by problems of congestion in curricula sometimes have more directive force than good pedagogical philosophy; and convenience of administration some-



Evolutionary trends in electrical-engineering curricula

Continuation of trend chart in the Report on Investigation of Engineering Education, 1923-29, Society for the Promotion of Engineering Education. Data for 1934 are from the questionnaires of the committee on engineering schools, Engineers' Council for Professional Development

times has more influence than the production of continuity of thought and endeavor for the students.

The evolutionary trends of every important branch of engineering practice result in constant demand for changes in engineering education, and the now notable tendency to establish experimental curricula or introduce newly defined experimental subjects of instruction seems to be legitimate and likely to continue but needs careful restraint in performance. The ECPD committee on engineering schools faced this situation with courageous wisdom tempered by cautious liberality.

EVENING CURRICULA AND CO-OPERATIVE COURSES

Out of changes in engineering affairs, and particularly changes of industry, have come the impulses that have produced evening curricula leading to engineering degrees and also those that have produced co-operative courses. Although undergraduate curricula are now under consideration it is to be remembered that these several threads of development also are appropriate for planned graduate work. It is becoming accepted that engineering schools located in centers of diversified industry have an obligation to the citizens of the community and to the industries to make engineering education possible to all who demonstrate competency, desire, and fitting personal qualities. Out of this situation has arisen the strong trend toward evening curricula in industrial cities.

The earlier evening schools were relatively meager and of thin quality, but the content of evening engineering curricula has come to equal in extent and grade the content of the day curricula in certain institutions. The arrangements for suitable engineering teachers in evening work are improving and the relations with industries whose employees pursue these evening curricula are also improving. The trend is toward full equality between day and evening curricula in those institutions that grant like degrees for both.

The trend in firmly established co-operative courses is toward periods of interchange between college and works longer than those Dean Schneider originally set up at the University of Cincinnati, with an approach to periods which are coterminous with regular college terms, as adopted at the Massachusetts Institute of Technology when the electrical-engineering co-operative course was established there. A tendency to reduce the extent of competent academic work which had appeared in some of such curricula apparently has been turned by the effect of consultations with the ECPD committee on engineering schools. The responsibility of industry for a mutual interest in the co-operative engineering courses is being more fully invoked, which adds generally to the welfare of engineering education. The depression has caused modifications of details in many instances, but the principle has survived its destroying influence unexpectedly well, and industry continues to turn favorably toward co-operation in various aspects of engineering education.

LACK OF CLEAR DEFINITIONS FOR GUIDES

The dynamic changes which have been affecting all important engineering branches have tended to blunt the keenness of definitions of the purposes of engineering education, as far as such existed. That is, the definitions of engineering education that are to be inferred from printed and spoken statements seem to grow less exact. Here is an important task that is open for the ECPD committee on engineering schools—that is, the formulation of a broad but convincing definition of the purposes of engineering education.

A notably fruitful trend is the increasing recognition that research is an important part of undergraduate engineering education, and that students in the upper classes should be made aware of its value and participate in it. However, it is not necessary to support elaborate graduate work or great research projects for the purpose of securing a substantial influence of research on undergraduates. That is being accomplished by the effect of suitable men on the staff in some institutions in which little or no formal graduate work is provided; but the spread of this tendency among such institutions is yet rather narrow and there are no clear-cut definitions of the possibilities by which administrative officers may be guided.

It is clear that there is an increasing recognition by the public in general that a superior order of intellectual qualities is required for gaining important achievements in engineering, and that superior moral qualities are required in support of the achievements when they are gained; also, that theory must be tempered with practicality in engineering; that character stands before knowledge among engineers; and that study of technical subjects teaches character in its features of intellectual honesty and steadfastness of purpose. It is equally clear that this growing public recognition increases the responsibility of the engineering schools and their faculties to produce education of high professional caliber in association with technical competency, but in this, again, clear-cut definitions are lacking.

ENGINEERING-SCHOOL FACILITIES

The lagging tendency in the development of interested participation by the teachers in professional engineering and professional educational matters (which may be an indication of their professional standing) may be illustrated by the extent of participation in professional society affairs. the accompanying table, based on figures from the ECPD report, shows the relationship between society membership and recognition in leading biographical directories.

Teachers for engineering schools are drawn from the institution in which they are chosen to teach, from some other institution, from engineering practice, or through some combination of these. There seems to be no appreciable change in the practices except that the greater engineering schools located here and there through the country are now more frequently than in the past securing for an important post some young man who has been proved worthy of his spurs in industry. The ECPD committee on engineering schools commented that "the securing of the right kind of teachers is a major problem in engineering education." It is only the exceptional institution to which there is no applicability for the comment,

Distinction of Full Professors in Five Major Engineering Fields, as Measured by Listings in Biographical Directories and Membership in Professional Societies*

Field of Engineering	Number of Professors	Percentage of Professors: American Men of Science — Starred†	American Men of Science — Listed (Inc. Starred)	Who's Who in America	Member of Engineering Society (Own or Other Field)	Member of Society for Promotion of Engineering Education
Chemical	99	6	79	28	59	46
Civil	347		62	28	70	68
Electrical	200	4	78	35	92	75
Mechanical	370		69	25	71	65
Mining and Metallurgical	111	2	86	43	72	37

* Engineering societies included are American Institute of Chemical Engineers, American Society of Civil Engineers, American Institute of Electrical Engineers, American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers. Figures are based on 1938 membership lists, except for ASME, for which 1937 membership list was used. Biographical directories used: American Men of Science, 1938 edition; Who's Who in America, 1938–39 edition.

† Indicates the 1,000 whose work is regarded as most important.

made by Dean A. A. Potter in his 'Report on the Engineering Schools of Land-Grant Colleges," that teaching staffs on the whole gave little observance to developing the most desirable processes for instruction of competent students. In some institutions the tendency for improvement is strong, but in many institutions it lags. Excessive teaching loads, insufficient salaries, isolated locations, lack of encouragement from executive officers who themselves are inadequately informed regarding the needs of engineering education, all may have a part in responsibility for this lag.

A wider adoption of reasonable retirement and pension policies is a desirable present trend in the treatment of engineering teachers. Salaries, extent of conventional teaching loads, and facilities provided for the teaching stand about stationary, except in some notable institutions. The selection of new staff members still seems to rest unduly heavily on academic degrees, although some engineering schools offset this by a large recognition of vivid experience in engineering practice, thus partially avoiding a policy of putting the degree first and the man second. It is moderately well recognized that an investigatory spirit and achievement are more important for an engineering teacher than higher degrees. But men of investigatory spirit and achievement have so many opportunities that the low level of salaries and unencouraging conditions of a considerable proportion of American engineering schools fail to attract such men.

Whatever trends the depression may have introduced in the procedure of selecting staff members, probably its greatest effect has been to decrease the flow into industry from among the younger staff members; thus reducing turnover among members of the staff and reducing the normal opportunities for retaining in the engineering schools only those whose spirit serves best for the place. It is not likely that any one can predict whether or not this will have an unfortunate future effect.

Competent engineering education demands an intimate interrelation of teaching, research, and engineering practice. The trend has been toward bringing research from a backward position to its proper place of equality among the trio; and this trend is now operating among those engineering schools which were slow in catching the impulse. Quite a few engineering schools which secured the research spirit fairly early and have cultivated it strongly tend to emphasize research as the major enterprise. This may be at the sacrifice of attention to both teaching and practice. The condition can be avoided by a staff possessing the fully developed professional engineering attitude that leads to intimacy with professional engineers through engineering societies and to intimacy with industry through conferences.

INSTITUTIONAL TRENDS

The old-time character of institutional jealousies has been for a considerable period in course of softening and this has resulted in a trend of potentially great importance, namely, co-operation between institutions, individually and by types. Unhappily, a trend now exists which disturbs the balance in the wider aspects of education within the field of engineering. This is the tendency of technical institutes to change into degree-granting engineering schools. The need in the engineering field is not for fewer students in the aggregate of those who are preparing for higher engineering work plus those who are preparing for the engineering trades, but for better-sifted engineering students in the engineering schools and an increased proportion of technical-institute students looking forward to the engineering trades. The tendency is in the opposite direction from the needs. Its strength is increased by the manner of administering engineer-licensing laws in several of the states, by which engineering-school graduates are credited with an equivalent of practice on account of their degrees while those without degrees do not secure such credits for their studies. This trend is causing more unbalance than ever of our already unbalanced educational provisions in the technical field. No means have been proposed for offsetting this unfortunate situation. A correct trend would be toward an increase in the number and excellence of technical institutes for training competent technicians in all industrial divisions of the country.

Illumination Notes

Floodlights for Night Baseball. The sixth major-league diamond to be floodlighted for night baseball will have its night premiere in June. The New York Giants have contracted for a floodlighting system for the Polo Grounds, which, it is said, will be the most powerful on any sports field thus far. Eight towers, 150 feet tall, carrying a total of 936 lights of 1,500 watts each, will be supplemented by additional lights on the grandstand roofs. The installation is further evidence that night baseball pays.

Contributed for the AIEE committee on production and application of light by L. A. Hawkins (A'03, M'13) executive engineer, research laboratory, General Electric Company, Schenectady, N. Y.

The Capillary Mercury Lamp as an Oscillograph Light Source

H. H. SKILLING
MEMBER AIEE

With the capillary mercury lamp as a light source, oscillograms may be recorded on bromide paper at speeds up to 50 feet per second

APPROXIMATELY twice as brilliant as a carbon arc, and some 12 times brighter than the filament of an incandescent projection lamp, the capillary mercury lamp is obviously a desirable light source for use with oscillographs. (See reference 1 for a short discussion of the optical systems of common types of oscillographs.) The capillary mercury lamp is a small quartz tube containing a small quantity of mercury, with an electrode at each end. When operating it passes current through mercury vapor at a pressure of 100 atmospheres or more. It was developed by Cornelis Bol, research associate at Stanford University, who did the initial work while with the Philips Lamp Works of Holland. Such lamps are now commercially available.

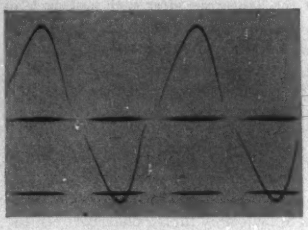


Figure 1. Oscillogram made with a capillary mercury lamp, operating on 60-cycle current, as light source. The wave is a record of lamp current

The advantages of the Bol lamp for the oscillograph are its ease of operation, and high intensity of light emission. Its brightness permits photographic speed greater than has previously been possible. For many purposes, however, a more important advantage is that it makes possible the use of relatively insensitive photographic media. Bromide paper, for instance, is much cheaper than film, as well as being easier to handle, and requires no photographic printing. Panchromatic emulsions are unnecessary with the Bol lamp, and its photographic speed is even greater than is indicated by its brightness, for the mercury light is of a highly actinic blue-white color. (See reference 2 for a spectrogram of light from a mercury lamp by Bol.)

The disadvantages of the mercury lamp are that it requires relatively high voltage (several hundred volts, depending on the design of the lamp); it is stroboscopic, going out between half cycles when operated on alternating current; and it requires a constant stream of cooling water.

Alternating current of the proper voltage can readily be obtained from a transformer connected to commercial power lines, but is unsatisfactory for oscillographic use because of the stroboscopic effect. Figure 1 is an example of an oscillogram for which the light source was a capillary mercury lamp operated on 60-cycle current. The wave shown is the actual lamp current, and as may be seen there is no trace while the current passes through zero.

To avoid the stroboscopic effect the lamp may be operated on direct current. This was done in obtaining figure 2, which is a record of an oscillatory transient current with a trace of a 60-cycle wave for calibrating the time scale. Figure 2 was made on photographic paper (News Bromide of the Eastman Kodak Company) at a paper speed of slightly less than four feet per second. Higher speeds are easily possible, and the first part of this same transient current appears in figure 3 as recorded at a speed of 16 feet per second. This was the mechanical limit of speed of the oscillograph, but the lamp is capable of recording on bromide paper up to speeds of 50 or more feet

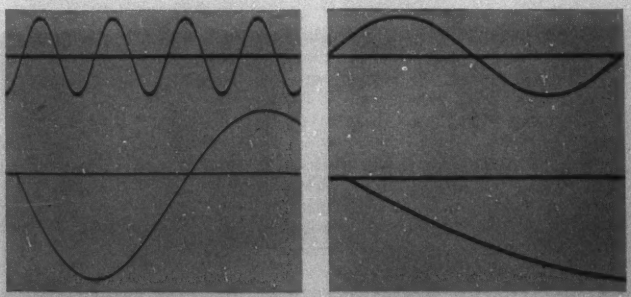


Figure 2 (left). Oscillogram made with a capillary mercury lamp, operating on direct current, as light source. One wave is a transient current, the other a 60-cycle timing wave

Figure 3 (right). Identical with figure 2, but at higher speed

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per second. With sensitive photographic film, speeds of several hundred feet per second could be used.

Photographically, the mercury lamp operating on direct current gives excellent results. But there are two electrical disadvantages to the use of direct current. The first is that a source of direct voltage of several hundred volts must be available. This requires either a special generator or a rectifier. It also increases the hazard; alternating current may be transformed to lamp voltage at the location of the lamp, while leads for high-voltage direct current must be carefully protected everywhere between the lamp and the d-c source. The second difficulty is in starting the lamp, for it will not always start on a voltage that is sufficient to maintain it in operation. With alternating voltage the crests of the waves provide a starting voltage that is greater by the square root of two than the effective operating voltage. When direct current is used it is satisfactory to apply operating voltage to the lamp and then to initiate the discharge with a spark from an induction coil that is connected (through a blocking capacitor) across the lamp. As an alternative means, a lamp that has been warmed up on alternating current will continue to operate if switched quickly to direct current of operating voltage.

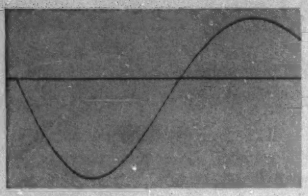

Figure 4. Oscillogram made with a capillary lamp, operating on 500-cycle current, similar to figure 2, except that no timing wave is required

A minor disadvantage of d-c operation is that the series ballast in the lamp circuit must be resistance instead of reactance, which reduces efficiency.

To avoid the disadvantages of both 60-cycle and d-c operation the lamp may be operated on alternating current of relatively high frequency. Figure 4 is similar to figure 2 except that the lamp was supplied with 500-cycle alternating current. The stroboscopic effect is still evident, but it is not objectionable as in figure 1. Indeed it is decidedly helpful, for each dot of the recorded trace represents $^1/_{1,000}$ second, and no auxiliary wave for timing purposes is needed. Intervals of time are measured by counting the dots, which give time in thousandths of a second with no measurement of distance or computation of any kind. The paper speed for figure 4 was 3.8 feet per second.

The intensity of the trace is greater with a-c operation, power input to the lamp and other conditions being the same, for the light intensity at the crests of the current cycles is greater than the steady light produced by the same effective value of direct voltage.

Figure 5 shows the actual lamp current, a 60-cycle wave, and a straight-line trace. The lamp current was of 500-cycle frequency, and its use as a measure of time is seen by reference to the 60-cycle wave. The record of lamp current shows that the light dims after each half cycle of current, but it is clear on the original oscillogram that there is nevertheless a continuous trace, showing that the lamp retains some brilliance even while the current is zero. (The mercury lamp, indeed, is brighter when it is "out", between half-cycles, than is the carbon arc at its brightest.)

Figure 6 is similar to figure 5, but with the speed of the recording paper increased to 16 feet per second. At this speed it appears possible that essential parts of the oscillographic record might be lost by taking place between the dots of the record, but apart from the fact that there is a visible trace connecting the dots it must be remembered that the time of relative dimness is about 0.0002 second, and a mechanical oscillograph will hardly respond with accuracy to any fluctuation in so short a time. However, there is no assurance of a complete record if the lamp is supplied with 60-cycle current, for not only is the interval longer, but also there is less persistence of luminosity to provide a continuous trace. It would be particularly unfortunate if a 60-cycle supply to the lamp were so synchronized with a 60-cycle wave being recorded that all the wave crests failed to appear on the oscillogram.

One of the minor advantages of 500-cycle operation of the lamp is the small transformer required, and the small inductance needed for ballast in the lamp circuit. The obvious disadvantage is that a source of 500-cycle power must be available.

The oscillograms shown were made with capillary mercury lamps of about 500-watt capacity. The lamps used have a luminous column of one-centimeter length.

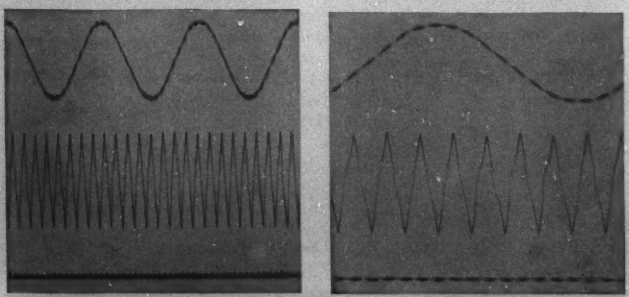

Figure 5 (left). Oscillogram made with a capillary mercury lamp, operating on 500-cycle current, as light source. The middle wave is a record of lamp current

Figure 6 (right). Identical with figure 5, but at higher speed

They operate on voltages between about 350 and 500 volts; at lower voltages their operation is unstable and at higher voltages their life is short. Actual operation was at 360 to 380 volts, for this gave sufficient light and the life is several times greater than at 500 volts.

Similar lamps, but with a 2.5-centimeter length and an 840-volt 1,000-watt rating, are commercially available. These give equally good results.

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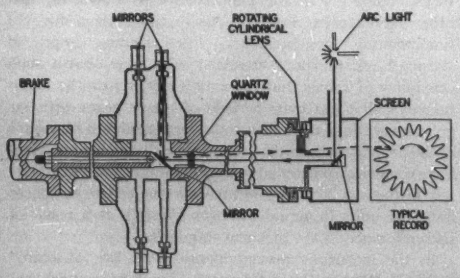
Blade Vibration Viewed in Experimental Turbine

SOME of the difficulties experienced with early superposed steam-electric turbogenerator units indicated a need for a better understanding of the conditions affecting the operation of turbine impulse blades in these machines. To obtain good economy at partial loads the incoming steam is fed to the first turbine wheel at only a portion of its periphery, and the blades passing into and out of this steam jet receive a most violent shock each revolution of the turbine. This method of loading has been used for many years with turbines operating at lower pressures, and it has been only on those few machines of the large superposed class, which operate at a pressure of approximately 1,200 pounds per square inch and a temperature of some 900 degrees Fahrenheit, that its use has caused some blades to break at the root where they are fastened to the spindle.

To enable the behavior of the turbine blades to be studied directly, an ingenious optical method has been devised whereby engineers literally can see inside the turbine while it is running and observe the vibration of the blades. As shown by the accompanying diagram, tiny mirrors are mounted inside the blades. A light beam projected through a hole in the turbine shaft is reflected by an inclined mirror through a hole in the spindle and blade to the mirror in the whirling blade being studied, and then back out through the shaft to a stationary camera or viewing screen. By taking pictures at short intervals on moving film, an exact record of blade performance may be obtained for any desired set of operating conditions. As may be seen by the typical record at the right of the diagram, the vibration of the blade is indicated by the oscillation of the light spot reflected back from the turbine blade around a circular path; if there were no vibration, the pattern would be a perfect circle.



Since September 1939, an experimental turbine of this type, built by the Westinghouse Electric and Manufacturing Company, has been under test in the South Philadelphia works of that company. More than 20,000 photographic records have been obtained showing the performance of impulse blades for a wide range of operating conditions. This machine operates at a pressure of 400 pounds per square inch and a temperature of 600 degrees Fahrenheit.

Studies so far show that the amount of load on a turbine has relatively little effect on the maximum blade stress. The factors that influence this condition are mechanical resonance and the damping characteristics of the bladesteel. It has been demonstrated that the impulse blading of large superposed turbines must be designed to operate at safe stresses under resonant conditions. The damping characteristics of different steels vary widely. The widely used 12-per cent chrome steel has more damping in its usable application range than any other material yet investigated. The materials of the chrome nickel class that excel in high strength at high temperatures have about one-tenth as much damping as the 12-per cent chrome steel. Damping becomes less as the frequency of vibration increases. This means that the increased stiffness of heavier blades does not result in much lower blade stresses. Damping decreases rapidly at higher operating temperatures, particularly beyond 750 degrees Fahrenheit.

The successful results obtained with the first machine has led to the design and construction of a larger experimental turbine by the Westinghouse company. This machine contains a full-size impulse wheel that is a duplicate of the first impulse stage of a 50,000-kw superposed unit and operates at a pressure of 1,250 pounds per square inch and a temperature of 900 degrees Fahrenheit. This turbine with its 10,000-kw generator and 15,000-horsepower water brake began testing operations in February in the Schuylkill plant of the Philadelphia Electric Company. The turbine takes steam from the station high-pressure steam lines and exhausts into the low-pressure lines permitting its operation as a superposed unit without interference with the station's regular operation. This turbine is built solely for research purposes and has many constructional features. The optical system will record the performance of 16 different blade combinations. Two rotors are being built with different blade designs. The use of the 10,000-kw generator will permit life tests on turbine blading by loading into the Philadelphia Electric system.

Revision of Electrical Units

E. C. CRITTENDEN
MEMBER AIEE

The international situation necessitated that the adoption of certain changes in electrical units which was to have taken place January 1, 1940, be indefinitely postponed. This article outlines the existing status of the changes, and also endeavors to clarify the proposed "mks" system of practical units, adoption of which has been advocated by the International Electrotechnical Commission. In addition, certain other proposals for adjustment of units are discussed.

ALTHOUGH world-wide agreement upon a system of practical electrical units was obtained many years ago, several different systems of units have remained in use for different purposes. Naturally some confusion has resulted from this diversity, and in recent years various proposals to bring about a closer approach to uniformity of practice have been seriously considered. In fact, so many such proposals, varying in details, have been made that they have caused further confusion of ideas. It has therefore been suggested that a simple statement of the more important projects for adjustment of the units would be useful. In such a statement it is not practicable to mention all the possible solutions that have been proposed, or to give credit to the individuals who have helped to clarify the problem. As a background, however, it appears necessary to review in part the history of our present common units.

THE INTERNATIONAL ELECTRICAL UNITS

The present international system of electrical units is the result of many compromises. The approximate magnitudes of the units came historically from units of resistance and electromotive force that had come into use because of their convenient size before any general system was accepted. Their exact magnitudes, however, were adjusted from time to time to make them consistent with the centimeter-gram-second (cgs) electromagnetic system; that is, the ohm was made as nearly as possible 10^9 cgs units, the volt 10^8 cgs units. A succession of International Electrical Congresses (1881, 1889, and 1893) developed definitions of the various units in which the cgs electromagnetic system was recognized as fundamental, but the ohm, ampere, and volt, respectively, were represented by specified physical standards (mercury column, silver voltameter, and Clark standard cell). After the Chicago Congress of 1893 a number of countries established by law units based upon the definitions adopted by that Congress. In the United States this was done by the Act of July 12, 1894.[1]

The resolutions of the Electrical Congresses and the United States law were formulated with the idea that there were no essential differences between the units represented by the physical standards and the corresponding multiples of the cgs units; and no clear distinction was made between the two systems. Such a distinction was made, however, by an official International Conference on Electrical Units and Standards held in London in 1908. It was then known that there were appreciable differences between the two systems; by a divided vote the Conference decided to retain the values represented by two of the physical standards, these being the mercury column for the ohm, and the silver voltameter for the ampere. The magnitude of the volt was to be determined in accordance with Ohm's law; this was done by an international technical committee in Washington in 1910, and the result was expressed by assigning a numerical value (1.0183 "international volts") for the electromotive force of the average Weston normal cell. At the same time there was adopted an "international ohm" as determined by measurements with mercury columns made at the national laboratories of Germany and Great Britain. In actual practice the two units then adopted have been the basis of practically all "international" units used since 1911.[2]

While the international units have been retained, the basis on which they were established has been practically abandoned. The mercury column and the silver voltameter were adopted as primary standards with the idea that any laboratory that chose to do so could reproduce them and thereby reproduce the units. In most of the larger countries, however, there are now national laboratories charged with the maintenance of standards, and other laboratories depend entirely upon them for the fundamental measurements. Furthermore, improved standard resistors and standard cells have shown such constancy of values that the units evidently can be maintained with them over periods of many years with far greater certainty than they could be reproduced by means of the primary standards. Consequently few observations have been made on mercury ohm columns or silver voltameters in the last 25 years, and in only one or two instances have the units in actual use been changed as a result of such reference to the primary standards.

In the meantime measurements made by "absolute" methods (that is, by reference to the fundamental mechanical units) showed definitely that the international ohm is about $1/20$ of one per cent larger than 10^9 cgs units of resistance,[3,4,5,6] while the international ampere is apparently $1/100$ of one per cent smaller than $1/10$ cgs unit of current.[7,8] The international volt and watt are there-

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1. For all numbered references, see list at end of article.

fore larger than the corresponding absolute units by about 0.04 and 0.03 per cent, respectively.

PROPOSED ADJUSTMENT OF UNITS—THE ABSOLUTE SYSTEM

Although there had been various proposals to establish a permanent international body to deal with electrical units, none had been formed up to 1921. A treaty signed in 1921 by representatives of the United States and 26 other countries and ratified in 1923[9] gave responsibility for those units to the existing organization for weights and measures. This organization consisted of the General Conference, a diplomatic assembly meeting at six-year intervals, the International Committee of 18 members elected as individuals, which meets at two-year intervals, and the International Bureau of Weights and Measures, a laboratory at Sèvres, near Paris. In order to fulfill its new responsibilities the General Conference of 1927 created a new branch of the organization, an Advisory Committee on Electricity with 10 members, including ex-officio representatives of six of the larger national laboratories.

The first problem before the new committee was to determine whether the international system of units should be maintained and perfected or whether the electrical units should be adjusted in some way to make them concordant with mechanical units. In anticipation of international action, the National Bureau of Standards put this question before American organizations, especially the AIEE.[10] After discussion in appropriate committees a resolution was passed by the board of directors of the Institute in June 1928, urging that researches be undertaken "in order that the absolute ohm and absolute ampere based on the centimeter-gram-second electromagnetic system, with the absolute volt, watt, and other units derived from them, may be legalized in place of the international ohm and ampere and their derived units." During the same year, at the request of the National Bureau of Standards, all the major American scientific and technical societies interested in electrical measurements appointed representatives on a special committee to consider this question, and this committee unanimously adopted a similar, but less specific, recommendation.

These American recommendations were unanimously accepted by the international Advisory Committee on Electricity at its first meeting in November 1928, and by the International Committee on Weights and Measures in 1929. The next General Conference (1933), at which 29 countries were represented, approved in principle the adoption of the absolute units and authorized the International Committee to fix a date for their introduction.

In 1935 the International Committee decided that all absolute measurements to be considered in establishing the units should be reported by the end of 1938 and that the new values of the units should be put into use January 1, 1940. In 1937 results reported by four national laboratories were sufficiently concordant so that the International Committee felt justified in publishing an estimate of the probable ratios of the old to the new units, carried to five decimal places, as follows:[11]

1 mean international ohm = 1.00048 absolute ohms
1 mean international volt = 1.00036 absolute volts

The first ratio was believed to be correct within two or three units in the last place given, but the uncertainty in the volt was greater.

The program laid out by the International Committee was not carried out because the German national laboratory, the Physikalisch-Technische Reichsanstalt, had not completed its absolute measurements in 1938 and the German authorities were not prepared to adopt the absolute units until the Reichsanstalt had itself determined their magnitudes. For the ohm the German values were in good agreement with those found in other countries, but there were differences in the absolute measurement of current from which the volt would be derived. The preliminary results of the Reichsanstalt indicated that the absolute ampere was at least one part in 10,000 smaller than had been found in other countries. Consequently the Advisory Committee on Electricity, which met in June 1939, was not able to assign precise values for standards in terms of the absolute units nor to agree upon a definite date when this could be done. The apparatus used in the Reichsanstalt measurements was practically a duplicate of the current balance used at the National Bureau of Standards; plans were therefore made to exchange coils and to compare details of procedure at the two institutions in order to find the cause of the discrepancy between results.

There was also some hope that the German authorities might agree to join in establishing units fixed by rounding off the mean of the determinations to parts in 10,000, leaving them subject to future adjustment of some parts in 100,000. This would make the ratios of the international to the new units 1.00050 for the ohm and 1.00040 for the volt.

These proposals were to have been taken up at meetings of the International Committee and the General Conference in October 1939, but the meetings were cancelled when war broke out. A change in units should be made only by common action of all important countries, and no further progress toward agreement can be made until peace is restored.

It may be observed that the changes proposed are merely adjustments of the ordinary, or practical, electrical units to make them concordant with the fundamental mechanical units, and the change in magnitude would not be greater than $1/20$ of one per cent for any unit.

The international bodies concerned have not prescribed any specific methods for carrying out the "absolute" measurements by which the electrical units are to be derived from the mechanical units. In fact, it is clearly understood that the use of different methods and apparatus is desirable in order to reduce the effect of systematic errors which might exist in any one method. The absolute measurements may be made by any method in accordance with the generally accepted principles of electromagnetism. The reference to the centimeter-gram-second system of units is immaterial so far as the magnitude of the mechanical units is concerned. The essential point is that, in addition to the mechanical units, some electromagnetic unit or constant must be used; in the cgs electromagnetic system this is supplied by taking the permeability of space (μ_0) as unity.

With regard to maintenance of the units for the periods

between redeterminations by fundamental measurements no essential change would be made from the present practice. Groups of standard resistors and of standard cells would still be used as the principal means of keeping constant values for the ohm and the volt in the national laboratories, and also the means of providing basic standards for other laboratories. Incidentally, in view of the frequent reference made to the ohm as a basic unit, it should be noted that, in the absolute measurements made up to the present time, both the ohm and the volt are secondary or derived units, because the electrical quantities actually determined by direct application of mechanical measurements are inductance and current.

THE METER-KILOGRAM-SECOND SYSTEM

While it is proposed to adjust the values of the electrical units as indicated above, the practical system is so firmly established that no proposal to change it radically can be considered. On the contrary, serious proposals have been made to extend the use of that system and to bring other units into concordance with it. In particular the continued use of the cgs system has been condemned, one reason being that a variety of powers of ten are required to convert from cgs electrical units to practical units.

If the second is retained as the unit of time, there are an infinite number of combinations of units of length and mass that will make equations including mechanical units concordant (or coherent) with the practical electrical system, all the necessary powers of ten being lumped into the value assigned for the permeability of space (μ_0). It happens that one of these combinations includes the two units, meter and kilogram, which are the real bases of the metric system. Consequently, if we use meters and kilograms instead of centimeters and grams in the fundamental electromagnetic definitions and equations, the ordinary units can be used for all the electrical quantities, provided that μ_0, with the numerical value 10^{-7}, is put in where it belongs. The use of the meter-kilogram-second system therefore involves no change whatever in the ordinary electrical units, if one disregards the small difference between international and absolute units, as is usually done in textbooks and theoretical discussions.

The introduction of mks units, however, radically changes the common usages in other fields, especially magnetism, where the cgs units are now largely used. It also makes necessary some new mechanical units, including a unit of force equal to 10^5 dynes, for which the name "newton" has been proposed.

Furthermore, there are several possible varieties of mks systems, one exactly analogous to the cgs electromagnetic system and others "rationalized". "Rationalization" means defining the units in such a way as to shift the factor 4π, which inevitably appears in some of the equations, to places that are believed to be more logical and convenient. Various methods of doing this have been proposed.[12,13,14,15,16] The International Electrotechnical Commission at its sessions of 1935[17] and 1938[11] "adopted" the mks system without reaching a decision on the question of rationalization, but the trend of practice among writers and teachers who have actually used the system seems to be definitely in favor of a rationalized system in which μ_0 is taken as $4\pi \cdot 10^{-7}$ instead of 10^{-7}, and the unit of magnetomotive force is the ampere-turn instead of the ampere-turn/4π.[18]

The IEC has no authority to require anyone to use the mks system. The "adoption" of the system is in effect simply a recommendation that it be used. At least one textbook using mks units has already been published;[19] and the system is being introduced into various college courses. If usage can be concentrated on some one mks system a very desirable simplification may result, even if the system is not accepted for all fields of work. It is not to be expected that the mks system will completely displace the cgs systems.

OTHER PROPOSED ADJUSTMENTS OF UNITS

The discovery that the electrical and the mechanical units could be so conveniently connected by using the meter and kilogram as indicated above was made by Professor G. Giorgi[20] of Italy, and in recognition of this contribution the IEC proposes to call the system the Giorgi MKS system. Giorgi's plan, however, went further than this. Giorgi's system was rationalized. Furthermore, instead of taking a value of permeability as the means of connecting the mechanical and electrical quantities, he took the ohm as a fourth fundamental unit. When it developed that the international ohm differed by a significant amount from the absolute ohm (10^9 cgs units), it was pointed out that the international ohm might be retained and the "MKSΩ" system (mechanical and electrical) could be made consistent by adjusting the other electrical units.[21] In Giorgi's system μ_0, instead of being taken as exactly $4\pi \cdot 10^{-7}$, would be an empirical constant. The numerical value of μ_0 would be determined by the same absolute measurements that are now being made to fix the size of the absolute units. Those measurements would also determine the changes necessary in other electrical units; such changes would in general be smaller than the change now proposed for the ohm.

When the IEC voted in 1935 to adopt the mks system there was considerable confusion with regard to the meaning of this action, since in fact the IEC has no authority to change the fundamental units. There was also some difference of opinion as to whether, for the purposes of the IEC, Giorgi's choice of the ohm as a basic unit was the best. Consequently the IEC asked the advice of other bodies with regard to the choice of a fourth unit, meaning to choose some one of the practical electrical units.

In the discussion regarding the "fourth unit" several different problems were confused. Besides the fundamental question of the basis to be adopted for determining the size of the units, arguments were advanced regarding the standards to represent the units in the laboratory, the choice of units to give convenient dimensional equations, and the sequence in which the units could most conveniently be defined. It appeared that for these different purposes different units might be selected as starting points for a system, and it was not clear which of these purposes the IEC committees had in mind. However, nearly everyone agreed that the basis for fixing the size of the units should be the electromagnetic system, and not any one of the

electrical units; that is, a value for μ_0 should be specified, and this value should be equivalent to the value $\mu_0=1$ for the cgs system. In 1938 the IEC decided to follow this advice, thus concurring with the decision previously made by the International Committee on Weights and Measures.

The decision that no one of the electrical units is to be arbitrarily chosen as a datum from which the magnitudes of other units and their correlating constants are to be derived need not prevent anyone from choosing any convenient set of units as a base for other purposes. The whole system of units is intended to be consistent, and no contradictions should result from starting at different points in it. For example, the practicable methods of obtaining electrical units precisely from mechanical measurements involve use of two electrical quantities (inductance and current) instead of only one, with the corollary that precise values of the watt or joule, instead of being obtained by application of the mechanical definitions, are always obtained from electrical measurements. The practicable methods of maintaining units precisely and of transferring them from one laboratory to another involve two other units, ohm and volt. Dimensions of quantities are not fundamental,[22,23,24] and there appears to be no reason why a writer may not choose as a basis for them any quantities which he finds convenient. Formal definitions cannot be made to accord with the actual procedure of setting up the units without making them excessively complex; it seems therefore reasonable to set up a series of definitions starting with any convenient unit.

CONCLUSION

The decision made by the official international organizations dealing with weights and measures to adopt the absolute practical electrical units in place of the present international units on January 1, 1940, could not be carried out on that date because agreement had not been reached on exact values for the absolute units. It is, however, quite certain that the change in the ohm will be a decrease of about 48 parts in 100,000; the volt will probably be decreased by 35 to 40 parts in 100,000; adjustments of other units follow from these two changes. Further comparisons of standards between the various national laboratories will be necessary before exact values can be established and a new date fixed for the change in units; such co-operative work cannot be carried on during the war, and consequently it is not now possible to say when the change will be made.

The action taken by the International Electrotechnical Commission in 1935 and 1938 in adopting or recommending the meter-kilogram-second system of units is only indirectly related to the adjustment of the magnitudes of the units. The use of the mks system involves no change in the practical electrical units, but its magnetic units differ from those commonly used. The IEC left to the future a decision between alternative locations for the factor 4π, which will affect the magnetic units. Many authorities, however, favor a rationalized system which makes the permeability of space $\mu_0=4\pi\cdot10^{-7}$ and the unit of magnetomotive force the ampere-turn. The mks system also introduces new mechanical units, including the "newton" which is equal to 10^5 dynes.

While the complete mks system advocated by the IEC applies precisely only when the absolute electrical units are used, this need not prevent its adoption in practice, since allowance can be made when necessary for the difference between absolute and international units, just as is done with other systems.

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Of Current Interest

Other Societies •

NRC Committee to Survey Research in Industry

At the request of the National Resources Planning Board (formerly the National Resources Committee) the National Research Council has undertaken a survey of the scientific research carried on by industry in the United States. The study is part of the Planning Board's program of evaluating the country's facilities for scientific work.

The report by the NRC will emphasize significant trends in the development of research by industry, the direct application of scientific knowledge to manufacture, the relation of research to the growth of various industries, and will also include a comparison of industrial research abroad with that in the United States. The NRC Directory of Industrial Research Laboratories, now in its sixth edition, will be revised completely in connection with the survey.

The NRC committee in charge of the survey includes the following AIEE members:

O. E. Buckley (M'19, F'29) executive vice-president, Bell Telephone Laboratories, Inc., New York, N. Y.

W. D. Coolidge (A'10, M'34) director of research, General Electric Company, Schenectady, N. Y.

Maurice Holland (A'23, M'30) director, division of engineering and industrial research, National Research Council, New York, N. Y.

F. B. Jewett (A'03, F'12) vice-president, American Telephone and Telegraph Company, New York, N. Y.

U. S. Committee, ICI, to Maintain Organization

Although the work of the International Commission on Illumination has been interrupted for an indefinite period by the war in Europe, the United States National Committee of the Commission proposes to maintain its organization, in order to resume activities as soon as the international situation permits, according to the report of the president for the year ending with October 1939. Expenses of the Committee in the meantime will be kept at a minimum, and only nominal dues collected. Constituent organizations are being urged to continue their participation by payment of such dues and appointment of representatives.

As publication of the proceedings of the tenth international sessions of the Commission, held in Holland June 10–21, 1939, is likely to be delayed by the war, a detailed report of the meetings has been prepared by the executive secretary of the United States National Committee and will be given considerable circulation, the president's report states.

AIChE Moves to New Quarters. Because of its growth in membership, the American Institute of Chemical Engineers moved its offices on April 1, 1940, from the Engineering Societies Building to the Chemists' Building, 50 East 41st Street, New York, N. Y. Membership in the society has increased from about 1,500 to 2,400 in the last three years. All activities connected with the publication of the *Transactions* will take place at the new offices.

Future Meetings of Other Societies

American Institute of Chemical Engineers. 32d semiannual meeting, May 13–15, 1940, Buffalo, N. Y.

American Physical Society. 234th meeting, April 25–27, 1940, Washington, D. C.

235th meeting, June 19–20, 1940, Seattle, Wash.

236th meeting, June 20–22, 1940, Pittsburgh, Pa.

American Society for Testing Materials. 43d annual meeting, June 24–28, 1940, Atlantic City, N. J.

American Society of Civil Engineers. Spring meeting, April 17–19, 1940, Kansas City, Mo.

Annual convention, July 24–26, 1940, Denver, Colo.

American Society of Heating and Ventilating Engineers. Semiannual meeting, June 17–19, 1940, Washington, D. C.

American Society of Mechanical Engineers. Spring meeting, May 1–3, 1940, Worcester, Mass.

Semiannual meeting, June 17–21, 1940, Milwaukee, Wis.

Edison Electric Institute. Annual meeting, June 3–6, 1940, Atlantic City, N. J.

Electrochemical Society. Spring meeting, April 24–27, 1940, Wernersville, Pa.

National Electrical Manufacturers Association. May 14–17, 1940, Hot Springs, Va.

National Fire Protection Association. Annual meeting, May 6–11, 1940, Atlantic City, N. J.

Society for the Promotion of Engineering Education. 48th annual meeting, June 24–28, 1940, University of California, Berkeley, Calif.

Society of Automotive Engineers. Summer meeting, June 9–14, 1940, White Sulphur Springs, W. Va.

Honors • • • •

Washington Award Announced for 1940

The Washington Award "in recognition of pre-eminent service in advancing human progress" has been conferred for 1940 upon Daniel Cowan Jackling, "for pioneering in large-scale mining and treatment of low-grade copper ores, releasing vast resources from formerly worthless deposits." Doctor Jackling, who is president of the Utah Copper Company, San Francisco, Calif., and a past president of the American Institute of Mining and Metallurgical Engineers, demonstrated the possibility of profitable exploitation of low-grade porphyry orebodies and was active in the formation of the Utah company to develop such ores. Among improvements in mining operations for which he was responsible have been the use of electric shovels for digging, steel construction in mill buildings, and three-phase alternating current in connection with hydroelectric developments. He received the John Fritz Medal in 1933.

A bronze plaque symbolizing the award will be presented to Doctor Jackling on April 15. He is the 17th engineer to receive the Washington Award since it was founded in 1916. Administered by the Western Society of Engineers in co-operation with the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE, the award is made annually, provided the members of the commission agree upon a deserving candidate.

Faraday Medal Awarded for 1939

The Faraday Medal, highest honor of the Institution of Electrical Engineers of Great Britain, was awarded for 1939 to Doctor Alexander Russell, past president of the Institution. Author of a life of Lord Kelvin and other works on physics and engineering, Doctor Russell is the 18th recipient of the award, which is bestowed for notable scientific and industrial achievement in electrical engineering or conspicuous service to the advancement of electrical science, without restriction as to nationality, residence, or membership in the society. Nine of the 18 recipients have been members of the AIEE, and three of these were Americans: Elihu Thomson, 1927; F. B. Jewett, 1934; and W. D. Coolidge, 1938.

Education • • •

Stevens Revises Courses. The junior laboratory course in electrical engineering presented at Stevens Institute of Technology is being revised with the assistance of a specially selected group of 24 members of the junior class. The group is working under direction on the development of 12 new experiments planned to broaden the department's curriculum for the junior and senior years. Lecture and laboratory courses in electrical engineering are required of all Stevens undergraduates. Much of the work formerly given juniors is now included in freshmen and sophomore courses under the physics department; the junior lecture course has been broadened to include study of a-c circuits and machinery,

formerly given to seniors; and the senior curriculum now provides more work than before in communications and electronics.

Short Management Course. A three-week course on motion and time study and related problems for executives, industrial engineers, cost accountants, and others, is being presented at the University of Iowa, Iowa City, June 10–28, 1940. Given last year for the first time, the summer management course is under the direction of Ralph M. Barnes, professor of industrial engineering, assisted by seven members of the University faculty. Visiting engineers and managers from industry will conduct forums on practical production problems.

Industry • • • •

Compressed-Air Circuit Breaker Given Demonstration Tests

A compressed-air circuit breaker developed by Westinghouse Electric and Manufacturing Company was given demonstration tests at the company's laboratory at East Pittsburgh, Pa., March 5, 1940, before more than 200 utility and industrial engineers.

The newly developed breaker was tested on power interruptions ranging from normal load current of 2,000 amperes at 13,200 volts to the three-phase 1,500,000-kva short-circuit capacity of the laboratory. Oscillograms made during the demonstration were said to show that all currents were interrupted at the first current zero, with about one-half cycle of arcing. No transient voltage greater than twice normal was observed.

The interrupting element of the compressed-air circuit breaker uses a cross blast of compressed air that passes between separated contacts in such a manner that the arc is driven against insulating splitter plates. By the time a current zero is reached an intense diffusive effect has de-ionized the arc space rapidly, causing the arc to be interrupted.

The demonstration included dismantling of the breaker to show the small amount of wear resulting from a series of operations. The component parts of the new unit are shown in the illustration.

All-Electric Streamliners. The Chicago, North Shore, and Milwaukee Railroad has ordered two all-electric streamlined passenger trains for high-speed operation between Chicago and Milwaukee. Believed to be the first of their kind to be put in use in the United States, each of the two complete four-car units will weigh light approximately 160,000 pounds, will be about 157 feet long, and will be capable of operating with the maximum load of 133 passengers at 80 miles per hour speed on 550 volts. Each unit will be powered with eight 125-horsepower 300-volt motors. Electric-pneumatic unit-switch control will provide for operation from either end of the four-car unit. The trains will be completely air-conditioned.

Television. A textbook on "Television—Electronics of Image Transmission," by V. K. Zworykin and G. A. Morton, has been published by John Wiley and Sons, Inc., New York, N. Y. Four major divisions, comprising more than 600 pages, treat the fundamental physical principles, the principles of television, the component elements of an electronic television system, and the RCA-NBC television project. Construction data for an experimental receiver are given. For those having access to laboratories, the description of apparatus has been made sufficiently complete to permit the construction of working models of pickup and viewing tubes in an elementary form. The book is priced at $6.

New Type Copper Introduced. Phelps Dodge Copper Products Corporation has announced the production of a new type of copper designed to eliminate the cause of 75 per cent of electrical failures, according to the company. Said to be almost as malleable as gold, the improved metal is made without melting from electrolytic cathode copper, plastically converted to commercial shapes at great pressure in a reducing atmosphere at high temperatures. It will be produced at a new plant at Bayway, N. J., and is expected to be particularly useful in airplane, submarine, and electric-locomotive power plants, the announcement states.

Tool Electrification Forum. The 1940 Machine Tool Electrification Forum will be held at the East Pittsburgh, Pa., works of the Westinghouse Electric and Manufacturing Company, May 6–8, 1940. Originally scheduled for April 29 to May 1, the dates of the forum have been changed to avoid conflict with other industrial meetings.

From AEC • •

ITEMS appearing under this heading are from the news service of American Engineering Council.

Supreme Court to Review Federal Rule Over Power

The much-disputed question of how far up the tributaries of navigable streams the Federal Government can constitutionally extend its authority has at last reached the Supreme Court of the United States, which on March 4 agreed to review lower-court decisions regarding the necessity for a Federal Power Commission license for the $11,000,000 hydroelectric development of the Appalachian Power Company on the New River at Radford, Va.

This case has had a tangled legal history extending over the last 15 years, during which the plant has been built and placed in operation. The power company has consistently refused to apply for a Federal license on the ground that the New River is not navigable and Federal jurisdiction does not apply. The Government contends that the New River is legally a navigable stream and that, furthermore, the project will affect navigation on the Kanawha River, into which it flows, and the Ohio River farther down. It asks an injunction prohibiting operation of the plant until a license is applied for and granted.

A ruling that the plant requires a license will subject the power company to certain requirements regarding operation of the plant, and will also mean that it can be recaptured by the Government at the end of 50 years.

Meanwhile Governor Leon C. Phillips of Oklahoma, who recently was refused permission by the Supreme Court to bring a suit to enjoin the construction by the Federal Government of Denison Dam on the Red River between Oklahoma and Texas, opened up a new battle by declaring that he would use troops, if necessary, to prevent the flooding of state roads and bridges due to the imminent completion of the Grand River Dam, a PWA-financed project being built by a state-created authority.

Engineering Projects Curtailed

Continuation of the drive by Congress to reduce below budget recommendations appropriations for the fiscal year beginning July 1, 1940, has resulted in a number of cuts affecting engineering work of various kinds.

The War Department appropriation bill for nonmilitary activities was reported to the House of Representatives only after its appropriations committee had eliminated a $15,000,000 item to begin the construction of a third set of locks for the Panama Canal. In its plan the committee recommended $850,000 for the preparation of plans and specifications, stating that to begin construction at present would be "premature." This action was upheld by the House itself in passing the bill.

Also eliminated from the bill was $800,000 for dredging a channel at Wake Island in the Pacific Ocean. As passed by the House,

the measure appropriated $70,000,000 for general flood control, or $63,000,000 less than the appropriation for the current year; $30,000,000 for flood control on the lower Mississippi River, a cut of $9,000,000; and $66,721,510 for river and harbor improvements, or nearly $30,000,000 below the current level. Also approved was $30,098,771 for work on the Panama Canal not connected with the new locks, but largely designed to strengthen its defenses.

Economy also trimmed the Interior Department appropriation bill, from which the appropriations committee cut almost $3,000,000, bringing the total down to about $119,000,000 as compared with $148,000,000 appropriated last year. Specific cuts included $1,247,000 from the United States Geological Survey, principally from a proposed fund for mapping strategic areas of military importance. This item represented an attempt to procure more funds for mapping, a proposal long favored by AEC. It was ruled out on the ground that an expenditure for military purposes should not be included in the Interior Department bill.

Library • • • •

OPERATED jointly by the AIEE and the other founder societies, the Engineering Societies Library, 29 West 39th Street, New York, N. Y., offers a wide variety of services to members all over the world. Information about these services may be obtained on inquiry to the director.

New Rules for Lending Books

With the object of making the Engineering Societies Library more useful to members, especially those prevented by distance from calling at the building, the library board has adopted the following rules for lending books:

1. Volumes from the library's general collection will be lent only to members in good standing of the founder societies and to nonprivate and noncommercial libraries. Volumes from the duplicate collection will be lent to any person establishing his responsible character to the satisfaction of the director.

2. Volumes declared by the director to be rare books or reference books will be lent only after approval by the executive committee.

3. Serial publications will be lent only after they have been bound.

4. A minimum charge of 50 cents per volume, which includes expense for insurance and postage to the borrower, will be made to all persons.

5. For each volume retained by the borrower longer than one week, a rental of 5 cents per day will be charged.

6. No volume from the library's general collection will be lent for a period longer than ten days, plus time for transit to and from the borrower, except with the specific approval of the executive committee.

7. No individual may have more than three volumes on loan in his name at any one time, and no library may have more than five volumes on loan in its name at any one time.

8. No loans will be made outside the continental United States and Canada.

It should be noted that while only members of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE may borrow books from the general collection, responsible nonmembers as well as members of the societies may borrow books from the duplicate collection. Bound volumes of periodicals are usually available for loan about two months after completion of the volume of the publication in question. The minimum charge of 50 cents per volume on loans is required from the local borrower who comes to the library in person, as well as from the borrower who uses the mails. Return mailing costs are paid by the borrower. The time in transit is not included in the length of time borrowers may retain books without additional charge (see 5).

Requests for loans should be addressed to the Engineering Societies Library, 29 West 39th Street, New York, N. Y. Members are asked to give their society affiliations when writing about loans.

Copies of Articles

Beginning March 1, the price of photostats is changed to 30 cents, including postage. Members of the founder societies can obtain a discount of 5 cents a print on personal orders, by mentioning the society to which they belong.

This price is for 11- by 14-inch white-on-black (negative) prints on bromide paper. Black-on-white (positive) prints can also be supplied by copying a negative print. These cost 30 cents in addition to the cost of the negative.

The prints contain one or two pages of the original paper, depending on its size. Reductions to approximately one-half or enlargements to approximately twice the original can be made, if desired, without extra cost. Unless enlargement or reduction is ordered, prints will be made the same size as the original.

Microfilm copies, on 35-millimeter film can also be supplied at a cost of 4 cents per exposure (usually one page), with a minimum charge of $1.25 per volume or piece.

For obvious reasons, copying is confined to library property. Where the library lacks what is wanted, it will arrange to get copies for members from other libraries or refer them to places where copies can be had.

MEMBERS MAY MAKE COPIES

For the benefit of members who wish to photograph material in the Library, a copying stand is available for use with the member's own camera.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Currents and Voltages of a Three-Phase Unbalanced Load

To the Editor:

In a Letter to the Editor, February 1940, W. H. Huggins gives what he apparently believes is a novel approach to the unbalanced wye problem. I should like to call to his attention that his method is really nothing but Doctor Kennelly's wye-delta transformation. The method of proof that he uses works as easily on the n-point star as on the three-point and is practically the standard method of proof. (See "Electric Circuits and Wave Filters", A. T. Starr, page 80.)

If one assumes that it is known that the equivalent electromotive force of a group of alternators in parallel is $E' = \Sigma yE/\Sigma y$

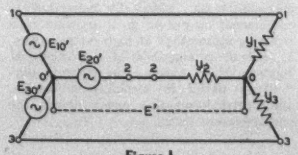

Figure 1

the results follow immediately as shown in figure 1.

The voltage

$$E' = E_{00'} = \frac{y_1E_{10'} + y_2E_{20'} + y_3E_{30'}}{y_1 + y_2 + y_3}$$

If now we let $E_{10'}$ become zero, so that 0' coincides with 1, and $E_{20'}$ and $E_{30'}$ become E_{21} and E_{31}, respectively, we have

$$E' = E_{00'} = E_{01} = \frac{0 + y_2E_{21} + y_3E_{31}}{\Sigma y}$$

or, reversing the voltage subscripts,

$$E_{10} = \frac{y_2E_{12} + y_3E_{13}}{\Sigma y}$$

$$I_1 = \frac{y_1y_2}{\Sigma y}E_{12} + \frac{y_1y_3}{\Sigma y}E_{13}$$

The other voltages and currents follow by cyclic order.

This method also works for an n-point star and, assuming the knowledge of alternators in parallel or Thevenin's Theorem, of which it is a particular case, is very brief.

V. G. Smith (A'26, M'35)

(Associate professor of electrical engineering, University of Toronto, Toronto, Ont., Can.)

To the Editor:

In his letter to Electrical Engineering, February 1940 issue, Mr. Huggins indicates a novel method of solving an unbalanced wye circuit. His solution, however, is only a corollary of the more general solution of the m-phase, star-connected system with a neutral return which was first developed by Professor Karapetoff. Since then, numerous variations have been made, of which Mr. Huggins' solution is one.

The basis of Professor Karapetoff's solution is the neutral-neutral voltage of which Mr. Huggins says ". . . . has but little meaning for unbalanced line voltages and is difficult to determine." The neutral-neutral voltage, or voltage residual, is the voltage between the neutral of the load and the neutral of the supply lines.

Professor Karapetoff's solution is given herewith. It was taken from the discussion of the article listed at the end of this letter. I have taken the liberty of adding another step to include the effect of the neutral return.

Let us consider the m-phase, star-connected, unbalanced load with a neutral return of admittance Y_N. Let E_{ON} be the voltage between the neutral of the line voltage O, and the neutral of the load N. Assuming all directions of current flow toward the load, then

$$\left.\begin{aligned} I_1 &= Y_1(E_{10} + E_{ON}) \\ I_2 &= Y_2(E_{20} + E_{ON}) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ I_M &= Y_M(E_{MO} + E_{ON}) \\ I_N &= Y_N E_{ON} \end{aligned}\right\} \quad (1)$$

where Y_M is the load admittance of phase M.

Remembering that $\Sigma I = 0$, we add and find

$$\left.\begin{aligned} Y_1E_{10} + Y_2E_{20} + \ldots + Y_ME_{MO} &= \\ &\quad -E_{ON}\Sigma Y \\ \frac{Y_1E_{10} + Y_2E_{20} + \ldots + Y_ME_{MO}}{Y_1 + Y_2 + \ldots + Y_M + Y_N} &= \\ &\quad -E_{ON} = E_{NO} \end{aligned}\right\} \quad (2)$$

This is the fundamental equation for the neutral-neutral voltage of an m-phase, star-connected system with interconnected neutrals, unbalanced supply voltages, and unbalanced loads. Substituting E_{ON} in equation 1 we may determine the desired currents and phase voltages.

Numerous particularizations may be made from these fundamental equations. Some of them are enumerated as follows:

1. The m-phase system may be reduced to the three-phase wye.

2. Unbalanced deltas may be solved by the same method, if they are first changed to unbalanced wyes.

3. The neutral return may be omitted by making $Z_{ON} = \infty$ and $Y_N = 0$.

4. The load-phase voltages may be given in terms of line voltages for a three-phase wye, thus:

with a neutral return

$$E_{1N} = \frac{E_{13}Y_1 + E_{13}Y_2 + E_{10}Y_N}{Y_1 + Y_2 + Y_3 + Y_N}$$

without a neutral return (Mr. Huggins' result)

$$E_{1N} = \frac{E_{13}Y_1 + E_{13}Y_2}{Y_1 + Y_2 + Y_3}$$

5. It may be used to check the vector wanderings of the load neutral under extreme conditions of unbalance, phase rotation, resonance, etc.

6. It may be used to solve cases of extreme unbalance such as the open delta or vee, single phase, etc.

A number of articles have been written on the possibilities of Professor Karapetoff's solution. One of them is "Floating Neutral n-Phase Systems," L. A. Doggett, AIEE TRANSACTIONS, volume 42, 1923, pages 1029–32; discussion, page 1350.

HERBERT SHERMAN (Enrolled Student)

(School of technology, College of the City of New York, New York, N.Y.)

New Indirect Luminaire Improves Drafting-Room Illumination

To the Editor:

F. P. Kuhl, in his article entitled "New Indirect Luminaire Improves Drafting-Room Illumination," (ELECTRICAL ENGINEERING, February 1940) showed one method by which a lighting installation may be improved and modernized to give better seeing conditions. As may be observed from his figures 4 and 5, the improvement in lighting was quite appreciable when the old-style milk-glass globes were replaced by specially developed louvered units utilizing 200-watt bowl silvered lamps.

It is the writer's desire to compare Mr. Kuhl's installation with one recently made in a drafting room of the American Gas and Electric Service Corporation. The latter installation made use of standard Chase Brass and Copper Company plastic bowl fixtures, bearing catalog number 1549, and utilizing 500-watt inside-frosted lamps in each unit. The spacing selected was 9 by 10 feet as determined from consideration of work- and reference-table layout and evenness of illumination upon the work plane. The fixtures were mounted with light centers 21/2 feet from the ceiling and 51/2 feet from the work plane. Twelve units were used in a room approximately 59 by 26 feet, so placed as to be in the center of a group of four tables consisting of two reference and two drafting tables back to back. This arrangement was the most economical one for the room and utilized the downward component of light to full advantage without causing shadows of annoying proportions. The units were selected for their efficiency and distribution characteristics, upon which preliminary design and layout calculations were performed and comparisons made with competitive units.

In comparing the two installations, one a result of specially developed lighting units and the other designed with standard economical units, the following tabulation may be helpful:

	New Louvered Unit	Standard Plastic Unit		
Lamp wattage	200*	200	300	500
Spacing	9 by 6 feet	9 by 6 feet	9 by 10 feet	9 by 10 feet
Watts per square foot	3.7	3.7	3.3	5.5
Foot-candles illumination	38**	27**	27	50
Principle of lighting	indirect	13 per cent direct; 74 per cent indirect		

* Silvered bowl lamp. ** See following discussion.

The data for the new louvered unit were taken from Mr. Kuhl's article. Utilizing these data for units placed on 9- by 6-foot spacing in the room described in the foregoing paragraph will afford a comparison with the plastic installation. Point-by-point calculations along the 6- and 9-foot spacings directly in line with the units yield illuminations varying between 27 and 34 foot-candles when all units that might contribute to that area are considered. Similar calculations on the plastic units with 200-, 300-, and 500-watt lamps yield average foot-candle values shown in the table. It is believed, therefore, that with the 9- by 6-foot spacings and 200 watts per unit the same magnitude of illumination is realized as with the new louvered fixture. The 38 foot-candles shown in the tabulation come about as a result of the contribution of other units, which would be necessary in a larger room such as that described by Mr. Kuhl.

The installation utilizing the standard plastic bowls made use of 9- by 10-foot spacing so as to minimize the number of units and therefore decrease the initial cost, as well as for the reasons previously given. With this spacing and 300-watt lamps the same magnitude of illumination may be obtained as in the previous case and with 3.3 watts per square foot, a decrease of 0.4 watts per square foot. It was felt, however, that a higher level of illumination should be maintained for the benefit of the draftsmen. This accounts for the use of 500-watt lamps and the realization of 50 foot-candles over the working plane. No part of the working area of similar height varies by more than 2 foot-candles.

This installation was made with a minimum initial investment, an item that is of importance when it is realized that the need for the installation may not exceed two years. In conclusion, therefore, it may be emphasized that:

1. Totally indirect lighting is not absolutely necessary for comfortable drafting-room lighting. Comparable shadowless lighting may be realized with semi-indirect fixtures, provided the downward component is not excessive. This installation utilized a 13 per cent downward component but it is believed that as much as 20 per cent would not prove annoying, provided the units are spaced correctly.

2. By making use of high-efficiency semi-indirect lighting units with low surface brightness, more foot-candles will be realized comfortably upon the work plane for a given initial investment and wattage per unit than will be attained with indirect units.

3. By using high-wattage lamps at greater spacings, the higher lamp efficiencies of these lamps may be incorporated into the over-all efficiency of the installation.

4. Proper control of light, such as its distribution, its result on the ceiling, on the work plane, color and level of intensity are the important features of drafting-room lighting that determine whether an installation results in comfortable shadowless glareless seeing conditions.

Thus two different attacks on the problem of drafting-room lighting have been presented. Mr. Kuhl preferred the totally indirect method utilizing a specially developed fixture. He maintains the level of illumination around 32 foot-candles. The plastic bowl installation uses a standard unit and realizes an initial average illumination of 50 foot-candles. It would be interesting to compare the economics of both installations. If both of the foregoing lighting units are considered to be equally

priced, it becomes evident that 40 per cent less would be expended initially for the plastic luminaires for equal average illumination (compare to the 300-watt lamps at 9- by 10-foot spacing). The plastic units would also require about 10 per cent less watts per square foot. In addition, by using standard lighting units, the development cost and the cost of placing the new unit into production are eliminated. The latter factors lead one to believe that the selling price of the newly developed unit would be greater than of the standard fixture, making the economy still more in favor of the standard plastic unit.

V. L. Dzwonczyk (A'36)

(Electrical engineer, American Gas and Electric Service Corporation, New York, N. Y.)

Membership Participation in AIEE Elections

To the Editor:

The letter of Paul MacGahan, printed in Electrical Engineering, February 1940, page 85, certainly should receive serious consideration by the committee on constitution and bylaws, and by the president himself. I agree with Mr. MacGahan most heartily, and suggest that headquarters do not even send out the silly ballots with the absurd provision for voting for only one person for each office, as only one name appears.

Several years ago, I observed here in our office among some 30 or 40 engineers, 10 or 15 of whom are members of the Institute, that *not a single man returned the ballot.* I took it upon myself to ask them if they had marked and sent in their ballots and they just laughed and pointed to the wastepaper baskets! So, I collected eight of these ballots and forwarded them to Headquarters, informing them that this was just a waste of money, and I did not even receive a reply.

A saving of $240 annually can be made in postage alone (16,000 at 1½ cents) by *not* sending the useless ballots, and further savings will accrue from the elimination of printing and associated expense. President Farmer's message in the November 1939 issue makes reference to the growing demands on the Institute's financial resources. Here is an opportunity to conserve some of the resources.

I have pointed out this letter of Mr. MacGahan's to several men who have been rather prominent in Institute affairs during the past several years, and they heartily agree with my recommendation. Several of these men are ex-chairmen of the Pittsburgh Section and others have had considerable to do on national committees, particularly membership. Two members in our department here in the Duquesne Light Company brought this letter to my attention—and these are real engineers, men who have been out of school some 10, 15, or 20 years. They are still members of the Institute, however, but are not really strong members because they feel that the Institute is not on the right track.

Now I know that the constitution and bylaws cover the provision for additional nominees other than those selected by the nominating committee, but it is never done and never will be done. This is well known by the president, the nominating committee, and the officers of the Institute, and by any others who have had much to do with the Institute affairs, but I doubt if the rank and file know it—and they are the ones that support the Institute financially.

B. M. Jones (A'20, M'24)

(Division engineer, Duquesne Light Company, Pittsburgh, Pa., and chairman, membership committee, Pittsburgh Section, AIEE)

Books Received

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

THE COMPLETE WELDER. Dealing with Up-to-Date Methods of Gas and Electric Welding. Three volumes. Volume 1, Non-Electrical Methods, Design and Testing. 464 pages; Volume 2. Electric Arc Welding. 432 pages; Volume 3. Resistance Welding. 432 pages. George Newnes, Ltd., London, W. C. 2, 1939. Illustrated, 9½ by 6 inches, cloth, £3 for three volumes. The three volumes of this set are composed of articles contributed by specialists, which are intended to cover every aspect of welding. The operation of equipment for all kinds of welding is explained, types of actual equipment on the market are described, and work under varying conditions and with different metals is discussed. All phases of the text are illustrated with photographs and diagrams. Volume III contains a classified key and an alphabetical index to the whole work, and 28 miscellaneous data sheets are contained in a separate cover.

THE ELECTRICAL YEARBOOK 1940. 33d Year. Emmott and Company, Manchester and London. 313 pages, illustrated, 7 by 4 inches, cloth, 1s.6d. Practical information and numerical data upon power-plant operation, electric motors, wiring, switchgear, metering, etc., for electrical contractors and others engaged in electrical work.

DIE ELEKTRISCHE KRAFTÜBERTRAGUNG. Volume 3. Bau und Betrieb alles Kraftwerkes, Part 2. By H. Kyser and K. H. Kyser. Third edition. Julius Springer, Berlin, 1940. 616 pages, illustrated, 9½ by 6 inches, cloth, 57 rm. The present instalment of the section in this treatise devoted to the construction and operation of power plants deals with the principles that determine the selection of continuous and a-c generators, the operation of the latter in parallel with switchgear and protective apparatus, and with the economic problems involved. The treatment is comprehensive, with emphasis upon principles rather than current forms of commercial equipment, and is intended to supply a practical text adapted to present needs. The volume completes this edition.

HIGH-SPEED DIESEL ENGINES. By P. M. Heldt. Third edition. P. M. Heldt, Nyack, N. Y., 1940. 475 pages, illustrated, 8½ by 5½ inches, cloth, $4.00. The purpose of this book is to discuss the principles involved in the design and operation of such engines, in the light of the research work that has been done here and abroad. Automotive, aircraft, and railroad engines are considered, with special reference to the needs of designers and experimenters. One chapter is devoted to miscellaneous types of oil engines. Differs little from preceding edition, but contains an appendix covering the developments in research during the interval.

HOCHFREQUENZKERAMIK. (Industrielle Keramik, Volume 2.) By E. Albert-Schönberg and others. Verlag von Theodor Steinkopff, Dresden and Leipzig, 1939. 171 pages, illustrated, 9 by 6 inches, paper, 8.25 rm.; bound, 9 rm. (in USA). An account by four specialists of the properties of porcelain as an insulator in high-frequency work and of the manufacture of porcelain insulators. The raw materials, methods of working them and combining them with metal and glass, the physical properties, and use of high-frequency porcelain, and the properties and construction of porcelain high-frequency condensers are described. Each section has a brief bibliography.

INDUSTRIAL ORGANIZATION AND MANAGEMENT. By R. C. Davis. Harper and Brothers, New York and London, 1940. 636 pages, illustrated, 10 by 6 inches, cloth, $5.00. Complete revision of the author's "The Principles of Factory Organization and Management", 1928. It attempts to draw a clear picture of the fundamental functions and principles of factory organization and management and their relations to one another, with discussion of specific problems, illustrated by examples of the solutions adopted by various factories. Bibliography.

INDUSTRIAL SURVEYS AND REPORTS. By W. Rautenstrauch. John Wiley and Sons, New York; Chapman & Hall, London, 1940. 189 pages, diagrams, etc., 9 by 6 inches, cloth, $2.50. This textbook outlines some of the problems engineers encounter in investigating and reporting industrial operations. The subject matter has been evolved from business and manufacturing experience, and actual situations are presented, with field investigation required for a number of the problems. Appendix A contains a report, embodying the results of investigating a particular company, which illustrates the material discussed in the text.

INTERIOR ELECTRIC WIRING AND ESTIMATING. By A. Uhl, A. L. Nelson, and C. H. Dunlap. American Technical Society, Chicago, 1940. 342 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. The methods, equipment, and materials for all kinds of interior wiring, from small jobs to apartment and factory buildings, are described in detail. The final chapter covers estimating electrical work, including both materials and labor costs. Eight blueprints giving the architectural drawings for a small house accompany the book.

LEGAL ASPECTS OF ENGINEERING. By W. C. Sadler. John Wiley and Sons, New York, 1940. 631 pages, 9 by 6 inches, fabrikoid, $4.00. Attempts to provide engineers with a general understanding of the legal principles that govern engineering practice and of their application by the courts. Over three hundred cases dealing with professional and industrial problems, aeronautics, property, and business, are presented.

MKS UNITS AND DIMENSIONS AND A PROPOSED MKOS SYSTEM. By G. E. M. Jauncey and A. S. Langsdorf. Macmillan Company, New York, 1940. 62 pages, diagrams, etc., 9 by 6 inches, cardboard, $1.00. In 1935 the International Electrotechnical Commission adopted the meter, kilogram, and second as the basic units of length, mass, and time, this action becoming effective in January 1940. This little book is intended to acquaint electrical engineers and physicists with the properties of this new system of basic units, to give reasons for the adoption of the ohm as the fourth basic unit, to describe a proposed meter-kilogram-second-ohm system of basic units, and to discuss the difference between magnetic flux density and magnetic field strength.

MATHEMATICAL METHODS IN ENGINEERING. By T. v. Kármán and M. A. Biot. McGraw-Hill Book Company, New York and London, 1940. 505 pages, diagrams, etc., 9 by 6 inches, cloth, $4.00. In this introduction to the mathematical treatment of engineering problems the authors present methods in connection with their practical applications in the fields of civil, mechanical, aeronautical, and electrical engineering.

PRACTICAL ELECTRIC METERING. By M. F. Smalley and others. John Wiley and Sons, New York; Chapman & Hall, London, 1940. 228 pages, diagrams, 9½ by 6 inches, cloth, $2.75. This book, based upon lessons from a school conducted by a large operating utility company, is designed as a textbook for metermen and others interested in meters. Following a review of the fundamentals of electricity, all makes and types of electric meters are discussed, with consideration of problems arising in connection with their construction and use.

PRINCIPLES OF INDUSTRIAL MANAGEMENT FOR ENGINEERS. By L. P. Alford. Ronald Press Company, New York, 1940. 531 pages, diagrams, etc., 9½ by 6 inches, cloth, $4.50. Presents and interprets the teachings of management as related to the present period of economic and industrial transition. The subject matter covers the evolution of industry and of management in industry, organization, and standards for the function of control, control of materials in manufacturing, time- and motion-study fundamentals, classification and cost accounting, maintenance, rate setting, wages, and industrial relations.

A TEXT BOOK ON LIGHT. By A. W. Barton. New York and London, Longmans, Green and Company, 1939. 426 pages, illustrated, 9 by 6 inches, cloth, $3.00. First treating the easily observed properties of light, then considering in detail the eye and the more important optical instruments, the book proceeds to a discussion of the theories of light, including such phenomena as interference, diffraction, polarization, etc. Illustrative examples accompany each chapter.

WHO GETS THE MONEY? By W. Rautenstrauch. Revised edition. New York and London, Harper and Brothers, 1939. 122 pages, charts, 8 by 6 inches, cloth, $1.50. In connection with an analysis of how the national income is spent, to whom it goes, and how it is used, proposals are made for a fuller application of productive capacity to the problem of feeding, clothing, and housing the 130,000,000 citizens of the United States.

Institute Activities

National • • • •

Summer Convention to Be Held at Swampscott, Mass.

The 1940 AIEE summer convention is being held at the New Ocean House, Swampscott, Mass., June 24–28. Members are reminded that, as the semi-annual meeting of The American Society of Mechanical Engineers is being held at Milwaukee, Wis., June 17–20, those traveling from the west may conveniently attend both meetings.

Tentative plans for the convention provide for a technical program of ten sessions, several technical conferences, and a general session. Arrangements have been made for a demonstration lecture on frequency modulation—the newest form of radio reception which entails a minimum of interference and noise.

The annual meeting of the Institute will be held Monday morning, June 24, followed in the afternoon by the first session of the conference of officers, delegates, and members, under the auspices of the committees on Sections and on Student Branches.

Trips to interesting places along the north shore of Massachusetts are being planned, and the bathing and sports facilities of the hotel, which are considered excellent, will be at the disposal of convention-goers. Special attention is being given to women guests.

The personnel of the summer convention committee is:

J. I. Hull, *chairman;* Thomas Cooper, Jr., and L. P. Shildneck, *vice-chairmen;* J. M. Murray, *secretary;* J. W. Lingary, *assistant secretary-treasurer;* C. L. Dawes, vice-president, North Eastern District; R. G. Lorraine, secretary-treasurer, North Eastern District; J. W. Barker, chairman, technical program committee; R. W. Adams, J. C. Balsbaugh, C. A. Corney, D. C. Jackson, H. A. McCrea, K. B. McEachron, I. E. Moultrop, F. L. Nason, J. G. Patterson, E. H. Raddin, C. F. Savage, Jr., A. C. Stevens, A. H. Sweetnam, and W. H. Timbie. *Subcommittee chairmen:* M. S. Wilson, *hotel and registration;* L. L. Edgar, *finance;* C. A. B. Halvorson, Jr., *entertainment and banquet;* I. A. Patten, *trips;* H. B. McIntyre, *sports;* G. J. Meyers, Jr., *transportation;* F. W. Bliss, *publicity;* E. A. Walker, *student activities;* Mrs. C. A. Corney, *women's entertainment.*

Executive Committee Meets

Meeting at Institute headquarters March 8, 1940, in place of the regular meeting of the board of directors, the AIEE executive committee heard a report from the special committee appointed by the board of directors to develop plans for radio talks on electrical-engineering subjects. Action was deferred to the next meeting of the board.

The committee authorized a joint session with the Institute of Radio Engineers, to be held during the Pacific Coast convention in Los Angeles, August 26–30. The dates October 9–11 were approved for the previously authorized Middle Eastern District meeting in Cincinnati, Ohio.

The following appointments were approved upon recommendation of the standards committee:

AIEE delegation, reorganized ASA sectional committee on storage batteries, C40:
C. J. Dempwolf Ralph Seabury H. N. Stover

Other actions included:

Approval of report of board of examiners meeting, February 21, 1940; action on recommendations as follows: 7 applicants transferred to grade of Fellow, 9 transferred and 28 elected to grade of Member, 184 elected to grade of Associate, 235 Students enrolled.

Approval of finance committee report: February disbursements $23,831.07.

Those present were:

Chairman—F. Malcolm Farmer
Members of committee—W. H. Harrison, K. B. McEachron, H. S. Osborne, John C. Parker, W. I. Slichter
Director—C. R. Beardsley
Chairman, special committee on radio talks on electrical-engineering subjects—C. R. Jones
National Secretary—H. H. Henline

District • • • •

General Committee Chosen for Middle Eastern District Meeting

Preliminary plans are in progress for the Middle Eastern District meeting at Cincinnati, Ohio, final dates for which have been set for October 9–11, 1940. The following have been appointed members of the general committee:

E. S. Fields, *chairman;* C. F. Lee, *vice-chairman, Subcommittee chairmen:* L. L. Bosch, *meetings and papers;* L. R. Culver, *student activities;* A. C. Burroway, *publicity and attendance;* J. A. Noertker, *inspection and transportation;* M. S. Schneider, *finance;* C. Fortenbaugh, *entertainment;* V. G. Rettig, *hotels and registration;* Mrs. J. A. Noertker, *women's entertainment.*

Section • • • •

Free Convention Trip for Winning Section Paper

To encourage papers by members of the Cleveland Section during 1940, Past President A. M. MacCutcheon has offered a free trip to the 1941 AIEE winter convention to the author of the best paper from a member of the Section this year. All members of the Section are eligible, except Enrolled Students in the Case School Branch, who may engage in a somewhat similar competition for the eastern division. The award defines expenses for the trip to the convention as equal to the amount allowed a Section delegate. Papers will be judged according to the rules governing National prize awards. A committee has been appointed to encourage the writing of papers and to direct their presentation.

New Section Elects Officers

At its organization meeting, held in Columbia, S. C., on March 2, the South Carolina Section (*EE, March '40, p. 130*) elected the following officers:

T. F. Ball, head of the department of electrical engineering, University of South Carolina, chairman

S. R. Rhodes, head of the department of electrical engineering, Clemson College, secretary-treasurer

Chairmen of three technical committees were appointed as follows:

Power—A. R. Wellwood, Columbia

Industrial Engineering—W. C. Boyrer, Charleston

Communications—A. B. Credle, Clemson

Further organization of technical committees was postponed to a program meeting, planned for the last week in April.

The meeting had an attendance of about 30 Institute members and interested nonmembers. F. R. Maxwell, Jr., professor of electrical engineering of the University of Alabama and Institute vice-president for the Southern District, was present at the meeting and helped the Section with organization details.

The following general committees have been appointed by the chairman:

Program committee: N. H. Coit, Columbia, chairman; F. T. Tingley, Clemson; J. E. Sirrine, Greenville

Membership committee: H. M. Stokely, Greenville, chairman; H. L. Stokes, Walterboro; C. O. Warren, Columbia

Bylaws committee: F. W. Chapman, Greenwood, chairman; G. R. Barksdale, Greenwood; O. L. Smith, Charleston

Informal Luncheons. Since March 1939 the Philadelphia Section has held informal weekly luncheons, which have become very popular. The largest attendance for a luncheon was 52, the average 22 members. Members attend as often as they wish. There are no speeches, schedule, toastmaster, or special menu. A special notice

Future AIEE Meetings

Summer Convention
Swampscott, Mass., June 24–28, 1940

Pacific Coast Convention
Los Angeles, Calif., August 26–30, 1940

Middle Eastern District Meeting
Cincinnati, Ohio, October 9–11, 1940

Winter Convention
Philadelphia, Pa., January 27–31, 1941

of the luncheons is sent out occasionally, and a brief announcement carried on the regular meeting notices. The luncheons are held at the Engineers Club, which is near the principal office buildings. A drawing is held each week for a complimentary luncheon. Since the luncheons were started, the American Society of Civil Engineers and The American Society of Mechanical Engineers have instituted similar luncheons for their members.

Communications Program Popular. Nearly 300 members and guests attended the February meeting of the Kansas City Section, the largest attendance of the current season and one of the largest ever secured at a technical session. More than 100 attended the dinner before the meeting. A. F. Rose, toll plant extension engineer, American Telephone and Telegraph Company, gave an illustrated lecture on multichannel carrier telephony, including demonstration of some characteristics of the feedback amplifier. A motion picture, "Dancing Telephone Cables," showing some extreme vertical vibrations in cables covered with ice, was presented by J. H. Schweitzer, Southwestern Bell Telephone Company, who discussed the methods employed in combating this action.

Discuss Registration Laws. To provide an opportunity for a full discussion of possible legislation on the registration of engineers, the Pittsfield Section held a meeting on January 30, to which all electrical, mechanical, civil, chemical, and other interested engineers in western Massachusetts were invited. The discussion was led by C. R. Beardsley, chairman of the Institute's committee on legislation affecting the engineering profession.

Other Clubs Entertained. Members of the Rotary and Kiwanis clubs attended a "Good Fellowship" meeting of the Lehigh Valley Section, at Bloomsburg, Pa., January 12, 1940. Features of the meeting were a turkey dinner, a talk on the mining, manufacture, and insulation of copper wire, a talk on the sterilization of milk by electricity, "good" singing by the Kiwanis Octette, and "loud" singing by all present. A total of 135 attended, 48 members and 87 guests.

Past Chairmen Honored. Following an annual custom of many years' standing, the Los Angeles Section celebrated "past chairman's night" at its regular February meeting. All past chairmen are invited to attend the dinner meeting as guests of the Section, one is appointed toastmaster, and each is introduced and given an opportunity to speak. Of 25 living past chairmen, 21 attended this year.

Bowling Tournament. About 60 members of the Boston Section took part last season in a bowling tournament sponsored by the Section. Alleys were reserved for an hour and a half preceding Section meetings, and an average of 20 members participated at each meeting. Small prizes for high total, high single string, and low man were distributed each time, and several grand prizes set aside for the season's winners, from among prizes donated by local electrical companies to be drawn at the annual dinner meeting at the close of the season. The cost of the bowling contests averaged between $4.00 and $4.50 per meeting, and the activity is regarded by the Section as having done more than any other in recent years to increase fellowship among the members.

Branch • • • •

Branch Greeted Over Television

Members of the Pratt Institute Student Branch received personal greetings over television from David Sarnoff (M'23) president, Radio Corporation of America, and an alumnus of Pratt Institute, James G. Harbord, chairman of the board of directors of Pratt, and John Hayes Hammond and Gano Dunn (A'91, F'12) members of the board, in a special broadcast to the Branch meeting February 1, 1940.

The Pratt Branch, membership of which represents 82 per cent of eligible students, publishes a monthly bulletin announcing its activities. It also has issued an "employment bulletin" containing photographs and records of the graduating class for the information of prospective employers.

Inter-Branch Get-Together. To encourage acquaintance and correlation of activities among the Branches of the New York metropolitan area, the College of the City of New York Branch held a smoker February 23, 1940. The gathering, the first of its kind in the area, was regarded as highly successful. Attendance from the various Branches invited was: CCNY, 68; Pratt Institute, 17; Columbia University, 7; Brooklyn Polytechnic Institute, 7; Cooper Union, 6; Rutgers University, 2; New York University, 1; Newark College, 0. Novel announcements in the form of blueprints were issued by the CCNY Branch.

Standards • • •

Subcommittee to Standardize Wet Testing

For a number of years there has been dissatisfaction in the industry in regard to wet testing of equipment because such standards as existed have not been conducive to consistent and comparative measurements. At one of the early meetings of the laboratory subcommittee of the joint committee on insulation co-ordination, the suggestion was adopted:

"that a common mode of procedure for the making of wet flashover tests be outlined to insure that the data obtained may be as nearly as possible on the same basis."

The laboratory subcommittee thereupon investigated the matter of laboratory procedure, such as the effect on the test results of different-shaped nozzles and water pressure, methods of measuring precipitation, correction factors for water resistance and for precipitation. As a result of their investigation over a number of years, they made certain recommendations which were included in a report presented at the 1940 winter convention of the Institute.

The laboratory subcommittee can, of course, only make recommendations and it is desirable that its work be carried forward to the point where a standard of wet testing can be included in the revision of test standards for those devices, such as insulators and bushings, that require wet testing. With this in view the AIEE standards committee, through its co-ordinating committee 3, has set up a subcommittee under the chairmanship of R. T. Henry to standardize the whole procedure of wet testing. The subcommittee hopes to arrive at a single rate of precipitation and a single value of the resistivity of water on which to base the results of wet tests on various kinds of apparatus, and thus facilitate apparatus testing.

Revision of AIEE Standard No. 1 Nearing Completion

The AIEE standards committee through its co-ordinating committee 4 has been engaged for some time in a revision of the pamphlet entitled "General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus", number one in the standards series.

Important recent trends to which consideration has been given in preparing these revised principles include:

1. The much greater use of enclosed or protected types of electric motors, making a change from the thermometer to the resistance method of temperature measurement logical.

2. The development of new insulating materials and methods of treatment, whose space-saving and heat-resisting qualities place greater emphasis on temperature limitations.

3. The opening up of new fields of application, such as aviation equipment and air conditioning, increasing the varieties of special purpose apparatus to be supplied by the electrical industry.

In preparing new or improved standards to cover the needs of the electrical industry, both theoretical and practical knowledge should be used to the fullest extent. Individual standards for specific types of apparatus should be correlated with each other to establish reasonable "temperature-rise levels" for electrical systems, thus improving momentary overload performance and promoting consistency in safety provisions. At the same time, it is important that individual types of apparatus and specific purpose applications should be free to use different temperature-rise values in accordance with their individual economic problems.

This revision of the original AIEE Standard No. 1 has been prepared in the hope that it will be useful in the continuing development of such a free but co-ordinated system of electrical standards.

The revised report was discussed at the March 26 meeting of the standards committee.

Personal • • •

AIEE Members Among Those Honored as "Modern Pioneers"

Awards were presented during February to 572 American scientists and inventors selected as "Modern Pioneers" in the National Association of Manufacturers' program celebrating the 150th anniversary of the American patent system (*EE, Dec. '39, p. 529*). Especially honored as national "Modern Pioneers" were 18 individuals and the group of 11 scientists responsible for the development of the new artificial fiber "Nylon". Among those honored for their contributions to the American standard of living during the last 25 years were the following members of the Institute:

National awards—**W. D. Coolidge** (A'10, M'34, Edison medalist) director, research laboratory, General Electric Company, Schenectady, N. Y.; **Lee de Forest** (A'04, F'18), Lee de Forest Laboratories, Los Angeles, Calif.; **C. F. Kettering** (A'04, F'14) vice-president in charge of research, General Motors Corporation, Dayton, Ohio; **V. K. Zworykin** (M'22) director, electronics research laboratory, RCA Manufacturing Company, Camden, N. J.

New York area—**H. A. Affel** (A'18, M'23) assistant director of transmission development, Bell Telephone Laboratories, Inc., New York, N. Y.; **H. S. Black** (A'23, M'33) technical staff, Bell Telephone Laboratories, Inc., New York; **J. R. Carson** (A'19, F'33) research mathematician, Bell Telephone Laboratories, Inc., New York; **Gano Dunn** (A'91, F'12, Edison medalist) president, J. G. White Engineering Corporation, New York; **G. W. Elmen** (M'21, F'27) research physicist, Bell Telephone Laboratories, Inc., New York; **H. C. Ford** (A'05) president, Ford Instrument Company, Long Island City, N. Y.; **A. N. Goldsmith** (M'15, F'20) consulting engineer, New York; **W. N. Goodwin, Jr.** (A'06, F'13) chief engineer and director of research, Weston Electrical Instrument Corporation, Newark, N. J.; **L. A. Hazeltine** (F'35) professor of physical mathematics, Stevens Institute of Technology, Hoboken, N. J.; **R. A. Heising** (A'15, F'39) radio research engineer, Bell Telephone Laboratories, Inc., New York; **C. J. Holslag** (M'19) president, Electric Arc Cutting and Welding Company, Newark; **D. S. Jacobus** (A'03) advisory engineer, The Babcock and Wilcox Company, New York; **B. W. Kendall** (M'18, F'29) toll development director, Bell Telephone Laboratories, Inc., New York; **Albert Kingsbury** (A'08) president, Kingsbury Machine Works, Inc., Philadelphia, Pa.; **R. H. Ranger** (M'22) president, Rangerstone, Inc., Newark; **H. E. Shreeve** (A'06, F'30) retired, American Telephone and Telegraph Company, New York; **W. R. Whitney** (A'01, Edison medalist) vice-president in charge of research, General Electric Company, Schenectady, N. Y. *Joint awards:* **T. M. Shrader** (M'30) in charge of radio tube advance development, RCA Radiotron division, RCA Manufacturing Company, Harrison, N. J.; **H. H. Beverage** (A'23, M'34) chief research engineer, RCA Communications, Inc., Riverhead, N. Y.; **C. W. Hansell** (A'23) transmitter research engineer, RCA Communications, Inc., Rocky Point, N. Y.; **G. L. Usselman** (A'24) radio engineer, RCA Communications, Inc., Rocky Point.

Baltimore area—**A. L. Penniman** (A'15, M'32) general superintendent, electric operations, Consolidated Gas, Electric Light, and Power Company, Baltimore, Md.; **F. E. Ricketts** (A'16), superintendent, electric stations, Consolidated Gas, Electric Light, and Power Company, Baltimore. *Joint award:* **P. L. Betz** (A'27) research physicist, Consolidated Gas, Electric Light, and Power Company, Baltimore.

Boston area—**H. E. Edgerton** (A'27, M'32) assistant professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass.; **H. E. Warren** (A'02, Lamme medalist) president, Warren Telechron Company, Ashland, Mass.

Chicago area—**W. A. Darrah** (A'09) president, Continental Industrial Engineers, Inc., Chicago, Ill.; **R. H. George** (A'24) assistant professor, electrical engineering division, engineering experiment station, Purdue University, Lafayette, Ind.; **G. A. Hughes** (A'17) president, Edison General Electric Appliance Company, Inc., Chicago; **H. L. Krum** (A'12, F'27) vice-president, Teletype Corporation, Chicago; **C. E. Lomax** (M'34) supervisor, automatic telephone system development, Associated Electric Laboratories, Inc., Chicago; **M. L. Nelson** (M'34) development engineer, Associated Electric Laboratories, Inc., Chicago; **W. M. White** (M'21) manager and chief engineer, hydraulic department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.; **John Wicks** (A'06) development engineer, Automatic Electric Company, Chicago.

Cleveland area—**Frank Conrad** (A'02, F'37, Edison medalist, Lamme medalist) assistant chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; **L. O. Grondahl** (A'26) director of research and engineering, Union Switch and Signal Company, Swissvale, Pa.; **J. K. Hodnette** (A'28, M'30) division engineer, distribution division, Westinghouse Electric and Manufacturing Company, Sharon, Pa.; **J. F. Lincoln** (A'08, F'39) president, Lincoln Electric Company, Cleveland, Ohio; **J. C. Lincoln** (A'07, F'32) chairman of the board of directors, Lincoln Electric Company, Cleveland.

Detroit area—**B. F. Bailey** (A'07, F'21) head of the department of electrical engineering, University of Michigan, Ann Arbor, Mich.

Hartford area—**H. J. Blakeslee** (A'02, M'15) president, The States Company, Hartford, Conn.

Los Angeles area—**Frederick Bedell** (A'91, F'26) R. C. Burt Scientific Laboratories, Pasadena, Calif.; **L. F. Hunt** (A'21, F'38) protection engineer, Southern California Edison Company, Ltd., Los Angeles, Calif. *Joint award:* **W. A. Schmidt** (M'22) president and general manager, Western Precipitation Company, Los Angeles.

Philadelphia area—**P. H. Chase** (A'12, M'18) chief engineer, Philadelphia Electric Company, Philadelphia, Pa.; **Francis Hodgkinson** (A'02) consulting mechanical engineer, New York, N. Y. (retired, Westinghouse Electric and Manufacturing Company, Philadelphia); **M. E. Leeds** (A'01, F'26) chairman of the board of directors, Leeds and Northrup Company, Philadelphia; **E. F. Northrup** (A'01, F'13) vice-president and technical adviser, Ajax Electrothermic Corporation, Trenton, N. J.; **D. C. Prince** (A'16, F'26) chief engineer, Philadelphia works, General Electric Company, Philadelphia.

Rochester area—**J. H. Levis** (A'21) circuit designer, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y.

San Francisco area—**H. E. Kennedy** (A'34) Berkeley, Calif.

St. Louis area—**F. B. Adam** (A'04) president, Frank Adam Electric Company, St. Louis, Mo.; **E. S. Pillsbury** (M'19) president and managing director, Century Electric Company, St. Louis.

E. G. Fox (A'12, M'20) vice-president, Freyn Engineering Company, Chicago, Ill., has been nominated as president of the Western Society of Engineers, for 1940–41. Born January 1, 1887, in Milwaukee, Wis., he received the degree of bachelor of science in electrical engineering from the University of Wisconsin in 1908. During the following year he was employed by the Northern Electric Manufacturing Company, Madison, Wis., and from 1909 to 1914 at the Fort Wayne (Ind.) works of the General Electric Company. He was an electrical engineer for the Mark Engineering Company, Evanston, Ill., 1914–16, and for the Steel and Tube Company of America, Indiana Harbor, Ind., 1916–20. He joined Freyn, Brassert and Company (later Freyn Engineering Company) consulting engineers, Chicago, in 1920. From 1928 to 1933 he spent much time in Leningrad, USSR, in connection with the development of the iron and steel industry. He was made a vice-president of the company in 1934. He is also a member of the Association of Iron and Steel Engineers and is the author of books and technical papers. He is at present second vice-president of the Western Society of Engineers.

F. H. Lane (M'23, F'37) manager, engineering division, Public Utility Engineering and Service Corporation, Chicago, Ill., has been nominated first vice-president of the Western Society of Engineers for 1940–41. Born June 7, 1882, at St. Louis, Mo., he received the degree of mechanical engineer from Lewis Institute in 1904. Following graduation he was employed as a draftsman by H. M. Byllesby and Company, Chicago, predecessor to the Byllesby Engineering and Management Corporation, which was later succeeded by Public Utility Engineering and Service Corporation. He was engaged in preliminary investigations of projects, 1906–08; was assistant superintendent of construction at Galena, Ill., 1909–10; and carried on general investigations and appraisals of public-utility properties, 1910–17, being placed in charge of the work in 1915. In 1917 he was made manager of engineering and construction, and with the formation of the present company, assumed the position of manager of the engineering division. He is a director of the AIEE, a member of The American Society of Mechanical Engineers, and at present is third vice-president of the Western Society of Engineers.

O. B. Coldwell (A'03, F'12) has retired as vice-president of the Portland General Electric Company, Portland, Ore., but will

continue with the company as consulting engineer. He was born November 28, 1875, at Salem, Ore., and studied electrical engineering at Stanford University and Cornell University, graduating from Cornell in 1902, with the degree of electrical engineer. During vacations and from 1893 to 1897 he worked in various capacities for the Willamette Falls Electric Company, Portland, and its successor, the Portland General Electric Company, and following graduation was employed by the latter as assistant superintendent. He became successively superintendent of the light and power department, general superintendent, vice-president in charge of transportation, and vice-president in charge of hydroelectric development and general construction. He has been a vice-president for 24 years, and in his association with the company and its affiliates has been active in most departments. He is a past president of the Northwest Electric Light and Power Association and has been active in committee work for the Edison Electric Institute and its predecessor the National Electric Light Association. He is also a member of Sigma Xi.

C. H. Sharp (A'02, F'12) president of the United States Committee of the International Electrotechnical Commission, has been elected honorary president of the Committee, succeeding the late Doctor A. E. Kennelly (A'88, F'13, HM'33). Born at Seneca Falls, N. Y., December 5, 1869, he received the degrees of bachelor of arts, Hamilton College, 1890, and doctor of philosophy, Cornell University, 1895, and also studied at the University of Leipzig, Germany. He was an assistant and instructor in physics at Cornell, Ithaca, N. Y., 1895 to 1901. He became test officer of the Electrical Testing Laboratories, New York, N. Y., in 1901, and vice-president and technical adviser in 1914, continuing to hold those positions until his retirement in 1933. He is the inventor of many instruments and author of many papers. He has served the USNC as delegate at 11 international conventions of the IEC, the first being at Turin, Italy, in 1911; as secretary 1921–23; and as president since 1924. He has also served as president of the United States National Committee of the International Commission on Illumination (1914–28), and is a past president of the Illuminating Engineering Society, and also a member of the American Physical Society, American Association for the Advancement of Science, Optical Society of America, and Société Française des Électriciens.

C. A. Robinson (A'11, F'22) formerly general manager, Chesapeake and Potomac Telephone Company, Washington, D. C., has been appointed vice-president and general manager. He was born September 26, 1881, in Anne Arundel County, Md., and received the degrees of bachelor of arts from Johns Hopkins University in 1903 and mechanical engineer from Cornell University in 1906. He was in the test department of General Electric Company, Schenectady, N. Y., 1903–04, and in 1906 entered the engineering department of the New York and New Jersey Telephone Company. He was transferred to the engineering department of the American Telephone and Telegraph Company in 1909, to handle transmission problems. In 1919 he was sent to Europe on a toll telephone cable project by Western Electric Company, and on his return was appointed transmission engineer, American Telephone and Telegraph Company. In 1920 he was made chief engineer of the Chesapeake and Potomac telephone companies, in 1929 assistant vice-president, and in 1931 general manager of the Chesapeake and Potomac Telephone Company of West Virginia. He was made general manager of the Washington company in 1936.

E. A. Graham (A'10, F'20) has been made manager of the engineering and research division of the United States Testing Company, Inc., with headquarters at New York, N. Y. The division has been created by the merger of the laboratory facilities of the company with the E. E. Free Laboratories, with which Mr. Graham has been associated for the past year. Born September 8, 1885, at Kelly, N. Mex., he received the degree of bachelor of science in mechanical engineering from New Mexico State College in 1906. From 1906 to 1914 he was engaged in electrical engineering for Westinghouse Electric and Manufacturing Company, Canadian Westinghouse Company, and Winnipeg (Can.) Electric Company. He became associated with Electric Bond and Share Company in 1914, working on engineering and economic investigations and as manager of properties in Latin American countries, until 1925. He was later national service manager and export manager for the Servel Corporation, and manager of sales in Cuba for the Detroit Graphite Corporation. From 1933 to 1938 he was on the staff of Sanderson and Porter, New York, N. Y., on industrial engineering work, before going to the E. E. Free Laboratories.

David Levinger (M'30) has been apppointed works manager, Western Electric Company, Inc., Hawthorne Station, Chicago, Ill. Born August 27, 1887, at Delta, Idaho, he was educated at Chicago Technical College. He was a steel inspector for International Harvester Company, Chicago, Ill., 1907–10. He has been with Western Electric since 1910, as mechanical engineer (1910–18), engineer of mechanical methods (1918–20), assistant technical superintendent (1920–22), assistant superintendent of development (1922–25), superintendent of manufacturing development (1925–28), and engineer of manufacture (1928–39). During the past year he has been assistant to the vice-president and works manager. He is also a member of the American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and American Association for the Advancement of Science.

W. G. B. Euler (A'08, M'33) has been appointed chief engineer of Pacific Gas and Electric Company, San Francisco, Calif. He was born in San Francisco, September 24, 1883, and received the degree of bachelor of science from the University of California in 1905. From 1905 to 1910 he was employed by General Electric Company on construction and engineering work on the Pacific Coast. In 1910 he was employed by the Great Western Power Company, San Francisco, as division superintendent, later becoming superintendent of operation (1919) and general superintendent in charge of operations (1929). When the company merged with Pacific Gas and Electric he was made general superintendent of the San Francisco and East Bay divisions, and will continue to act in that capacity in addition to his duties as chief engineer.

A. F. Dixon (A'14, F'26) formerly director of systems development, Bell Telephone Laboratories, Inc., New York, N. Y., has been made an assistant vice-president. As of April 30, 1940, he is retiring at his own request. He was born at Victoria, Ill., December 5, 1877, and studied at Armour Institute. He was employed by the B. F. Goodrich Company, Akron, Ohio, and the Stirling Company, Barberton, Ohio, before becoming a draftsman for Western Electric Company, Chicago, Ill., in 1902. In 1905 he was transferred to the development engineering department at Chicago, and in 1907 transferred to New York. He was placed in charge of printing telegraph organization in 1911, and of the development of machine switching systems in 1916. In 1919 he was placed in charge of all telephone systems development in the laboratories of Western Electric, and continued with that work after the establishment of Bell Telephone Laboratories. He holds many patents for telephone and telegraph apparatus.

William Wilson (M'23) formerly assistant vice-president, Bell Telephone Laboratories, Inc., New York, N. Y., is now chairman of the consulting staff, and also assistant vice-president in charge of labor relations, as part of a general rearrangement of the personnel organization of the Laboratories. Other changes in position or title include: **Lloyd Espenschied** (A'18, F'30) formerly research consultant, now consulting engineer; **C. W. Green** (A'10, F'40) formerly carrier telephone engineer, now consulting engineer; **Harry Nyquist** (M'24) formerly telephone engineer, American Telephone and Telegraph Company, now consulting engineer at Bell Laboratories. Among positions, reporting to director of apparatus development, changes include: **William Fondiller** (M'15, F'26) formerly electrical apparatus director, now assistant director of apparatus development; **H. A. Frederick** (A'12, F'28) formerly electromechanical apparatus director, now director of switching apparatus development; **R. A. Haislip** (A'21, M'21) formerly outside plant development engineer, now director of outside plant development; **W. H. Martin** (A'14, F'30) formerly switching research director, now director of station apparatus development; **G. D. Edwards** (A'16, M'26) formerly inspection engineer, now director of quality assurance. Reporting to director of research, changes include: **B. W. Kendall** (M'18, F'29) formerly toll development director, now director of circuit research; **Ralph Bown** (M'30) formerly radio research director, now director of radio and television research. **A. B. Clark** (M'19, F'30) formerly director of transmission development, is now director of sys-

tems development, heading both the transmission development and systems development departments, which have been merged. He succeeds **A. F. Dixon** (A'14, F'26) now assistant vice-president. Other changes in that department include: **H. M. Bascom** (M'19, F'30) formerly local facilities director, now director of switching engineering; **R. G. McCurdy** (A'16, F'34) assistant director of transmission development, now director of transmission engineering; **D. A. Quarles** (A'23, M'29) formerly outside plant development director, now director of transmission development; and **Morton Sultzer** (A'13, M'34) formerly protection development service engineer, now executive assistant.

R. W. Beck (M'37) formerly an electrical engineer for the Bonneville power project, has been named manager of the Gray's Harbor, Wash., Public Utility District. He was consulting engineer for the District during the survey of the holdings of the Gray's Harbor Railway and Light Company. A native (1896) of Chicago, Ill., Mr. Beck attended Oregon State College, and was employed by the Montana Power Company and the California Oregon Power Company before becoming an engineer for the City of Seattle (Wash.) Department of Lighting in 1925. He was made an utility engineer for the Department in 1936, and was also consultant for various public power projects in the state of Washington. In 1937 he was engaged to make valuation studies of privately owned utilities in Nebraska for the several public power districts of the state. He was later an electrical engineer on the Bonneville project, Portland, Ore., and was recently appointed consulting engineer by the Klickitat County (Wash.) Public Utility District.

W. W. Truran (A'23, M'30) formerly general toll engineer, New York (N. Y.) Telephone Company, has been appointed chief engineer of the Long Island area. He was born May 25, 1894, at Milbank, S. Dak., and received the degree of bachelor of science in electrical engineering from the University of Wisconsin in 1917. He was employed by the New York Telephone Company as engineering assistant in the same year, and was appointed assistant engineer in 1921. In 1925 he was made engineer in charge of toll fundamental plans, and in 1928, general toll engineer. **A. A. Williamson** (M'22) formerly engineer of transmission and protection, Long Island area, has been appointed general toll engineer, New York Telephone Company. He was first employed by the Bell system in 1909, following graduation from Stevens Institute with the degree of mechanical engineer.

J. R. Kearney (M'25) president and founder of the Kearney Corporation, manufacturers of utility equipment, St. Louis, Mo., has become chairman of the board of the company. Born in Louisville, Ky., July 2, 1878, he began work in 1893 on construction and engineering jobs. Employed by the W. N. Matthews Corporation, St. Louis, as sales engineer in 1906, he continued with the company 20 years, becoming district sales engineer, and later director of electrical sales. He organized his own company in 1926 and has served as president ever since. **W. A. Heinrich** (A'19, M'35) has been made executive vice-president and director of engineering of the Kearney Corporation. A native (1896) of St. Louis, he was associated with the W. N. Matthews Corporation from 1913 to 1926. He was one of the organizers of the Kearney Corporation, becoming its chief engineer. He has been a vice-president since 1930.

J. T. Littleton (A'23, F'28) who has been chief of the physical laboratory, Corning Glass Works, Corning, N. Y., since 1917, has been appointed to the newly created position of assistant director of research. Born at Bellehaven, Va., July 7, 1887, he received the degrees of bachelor of arts, Southern University, 1906; master of arts, Tulane University, 1908; and doctor of philosophy, University of Wisconsin, 1911. He was a teaching assistant at Wisconsin 1909–11, and instructor in physics at the University of Michigan, Ann Arbor, 1911–13. He became associated with the Corning laboratory as a physicist in 1913 and was made chief four years later. He is also a member of the American Ceramics Society, American Physical Society, American Association for the Advancement of Science, American Optical Society, and American Society for Testing Materials.

R. H. Van Horn (A'22, M'36) formerly chief engineer, United Illuminating Company, New Haven, Conn., has been appointed a vice-president of the company. He was born March 9, 1893, at Lambertville, N. J., and received the degree of bachelor of electrical science from Brown University in 1917. He entered the student course of General Electric Company, Schenectady, N. Y., in the same year, returning in 1919 after two years' service in the United States Army. In 1920 he became an engineer for General Electric and continued with the company until 1928, when he joined the United Illuminating Company as an engineer. He was made manager of the Bridgeport division of the latter company in 1930, and later became chief engineer.

E. F. Nuezel (A'27, M'39) superintendent, underground electric transmission and distribution department, Cincinnati (Ohio) Gas and Electric Company, has been elected president of the Technical and Scientific Societies Council of Cincinnati. He served as vice-president of the Council last year.

R. W. Eaton (A'07, M'13) formerly pubiic service and traffic engineer for the City of Providence, R. I., has been assigned full-time duties as traffic engineer, concentrating upon problems of highway safety and related topics.

F. J. Leerburger (A'28, M'35) recently appointed principal valuation engineer for the New York State Public Service Commission, has opened his own office in New York, N. Y., as a practicing consulting engineer.

H. P. Liversidge (A'12, M'17) president, Philadelphia Electric Company, Philadelphia, Pa., has recently been elected a member of the board of managers of the Franklin Institute.

H. L. Miller (A'38) president, Utilities Engineering Company, Philadelphia, Pa., has been elected vice-president of the Electrical Association of Philadelphia for 1940.

R. K. Lane (M'37) vice-president, Public Service Company of Oklahoma, Tulsa, has been elected a vice-president of the Oklahoma Utilities Association for 1940.

Obituary • • •

James Ewart Taggart (M'37) executive engineer, electricity branch, Punjab Public Works Department, Lahore, India, died some time ago, according to information just received at Institute headquarters. He was born at Castletown, Isle of Man, British Isles, April 23, 1896, and graduated from Faraday House Electrical Engineering College, London, England, in 1922. He became a student apprentice with the English Electric Company, Ltd., Preston, in 1921, assistant production and test engineer, 1922, and assistant to the general works manager at the company's main office in London in 1923. In 1926 he became assistant transmission and distribution engineer for the Burmah Oil Company, Ltd., continuing with the company until 1928. From 1928 to 1931 he was transmission-line engineer and later district engineer for the Perak River Hydro-Electric Power Company, Ltd., Malaya. Returning to England in 1931 he was construction engineer for the J. L. Eve Construction Company, Ltd., London, and for the North Eastern Electric Supply Company, Ltd., Newcastle-on-Tyne. He had been with the Punjab Public Works Department since 1934. He was also a member of The Institution of Electrical Engineers of Great Britain.

Carl Dunham Knight (A'05, M'13) professor of experimental electrical engineering, Worcester Polytechnic Institute, Worcester, Mass., died February 28, 1940. He was born at Putney, Vermont, October 14, 1880, and received the degrees of bachelor of science in 1903 and electrical engineer in 1908 from Worcester Polytechnic Institute. He spent the following year in the testing department of General Electric Company, Schenectady, N. Y., and in 1904 became an instructur in electrical engineering at Worcester Polytechnic. He became assistant professor of experimental electrical engineering in 1908, and full professor in 1920. Since 1906 he had held the position of superintendent of electrical maintenance for the institution, duties of which included designing light and power installation for new construction. He was Student Branch counselor at Worcester Polytechnic 1931–38, and was also a member of the Society for the Promotion of Engineering

Education, Illuminating Engineering Society, Tau Beta Pi, and Sigma Xi.

George Sanford Davis (A'04, M'12) assistant electrical engineer, Department of National Defense, Ottawa, Ont., Can., died December 29, 1939. He was born November 28, 1874, at Cincinnati, Ohio, and educated there. He was employed by Cincinnati utility companies, 1893–95, and later engaged in electrical contracting work for himself and for others. He was employed by the Niagara Falls Hydro Power and Manufacturing Company, Niagara Falls, N. Y., 1897–99, and in 1900 went with the Shawinigan Water and Power Company, Shawinigan Falls, Que., Can. In 1905 he joined the Canadian General Electric Company as construction superintendent. He was later district engineer in Ottawa and in Montreal. He entered consulting practice in 1920. Since 1937 he had been with the Department of National Defence in Ottawa. He was also a member of the Engineering Institute of Canada.

Irwin B. Hopkins (A'37) electrical draftsman, City Transit Department, City of Philadelphia, Pa., died January 12, 1940. He was born at Brooklyn, N. Y., November 8, 1894, and graduated in industrial electrical engineering from Pratt Institute. He was employed as an electrical draftsman by Krantz Manufacturing Company, Brooklyn, 1917–19, and by the Brooklyn Edison Company, 1919–20. From 1920 to 1924 he was an insurance surveyor and inspector for the Sanborn Map Company, Pelham, N. Y. He was employed by the Philadelphia Electric Company, Philadelphia, Pa., on substation design from 1924 to 1931, later becoming an electrical designer for the United States Navy at the Philadelphia Navy Yard. He had been with the City Transit Department since 1936.

Membership

Recommended for Transfer

The board of examiners, at its meeting on March 14, 1940, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the national secretary.

To Grade of Member

Anfang, B. L., coil designer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

de la Rosa, J. C., electrical superintendent, Toronto Transportation Commission, Toronto, Ont., Can.

Hentzen, H. K., exchange plant engineer, Southwestern Bell Telephone Company, Wichita, Kans.

Hollister, J. W. A., assistant electrical engineer, The Howard P. Foley Company, Inc., Washington, D. C.

Joseph, J. S., equipment engineer, Southwestern Bell Telephone Company, Oklahoma City, Okla.

King, F. H., superintendent, electric light department, Burlington, Vt.

Koopman, R. J. W., assistant professor of electrical engineering, University of Kansas, Lawrence.

Ochsner, W. W., electrical engineer, Southwestern Light and Power Company, Lawton, Okla.

Palmer, S. G., professor of electrical engineering, University of Nevada, Reno.

Scheer, G. B., consulting engineer, San Francisco, Calif.

Shelley, P., assistant electrical engineer, Oklahoma Gas and Electric Company, Oklahoma City.

Vivian, J. H., protection engineer, Southern California Edison Company, Ltd., Los Angeles, Calif.

12 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before April 30, 1940 or June 30, 1940, if the applicant resides outside of the United States or Canada.

United States and Canada

I. NORTH EASTERN

Abell, E. D., General Electric Company, Lynn, Mass.

Acord, T. E., General Electric Company, Schenectady, N. Y.

Alla, F. V., Hygrade Sylvania Corporation, Salem, Mass.

Anderson, C. H., New York Telephone Company, Albany, N. Y.

Anderson, D. P., General Electric Company, Pittsfield, Mass.

Andrews, G. E., Jr., Narragansett Electric Company, Providence, R. I.

Baker, J. M., General Electric Company, Lynn, Mass.

Baldwin, P. B., General Electric Company, Schenectady, N. Y.

Beardslee, R. F., Connecticut Light and Power Company, Waterbury.

Bell, N. R., General Electric Company, Lynn, Mass.

Blake, A. B., Jr., General Electric Company, Lynn, Mass.

Burley, C. F., Machlett Laboratories, Inc., Springdale, Conn.

Butler, J. B., Hamilton Standard Propellers, East Hartford, Conn.

Camp, R. C., General Electric Company, Schenectady, N. Y.

Carr, M. K., Spencer Lens Company, Buffalo, N. Y.

Clift, C. W., 210 Pleasant Street, Whitman, Mass.

Congdon, M. H., Electric Specialty Company, Stamford, Conn.

Copp, J. H., General Electric Company, Schenectady, N. Y.

Dianosich, C. S., Hanna Furnace Corporation, Lackawanna, N. Y.

Diehm, W. A., General Electric Company, Schenectady, N. Y.

Dodd, M. D., General Electric Company, Pittsfield, Mass.

Doran, R. J., Central New York Power Corporation, Watertown, N. Y.

Durgin, H. L. (Member), Central Vermont Public Service Corporation, Rutland, Vt.

Faulkingham, L. H., New Hampshire Gas and Electric Company, Portsmouth, N. H.

Glick, S. G., General Electric Company, Schenectady, N. Y.

Goldstein, G. D., 407 Oxford Street, Rochester, N. Y.

Hambrick, R. D., General Electric Company, Schenectady, N. Y.

Hilden, W. C., General Electric Company, Schenectady, N. Y.

Humphrey, C. D., Western Massachusetts Companies, Springfield, Mass.

Hyland, J. L. (Member), Turners Falls Power and Electric Company, Turners Falls, Mass.

Jamieson, G. E., General Electric Company, Schenectady, N. Y.

Johnson, I. B., General Electric Company, Schenectady, N. Y.

Kimball, R. E., General Electric Company, Schenectady, N. Y.

Kitzmiller, M. W., General Electric Company, Schenectady, N. Y.

Lasher, C. C., General Electric Company, Schenectady, N. Y.

Little, G., Jr., General Electric Company, Schenectady, N. Y.

Morris, L. F., General Electric Company, West Lynn, Mass.

Muir, W. A., General Electric Company, Schenectady, N. Y.

Nichols, A. J., Buffalo Niagara Electric Corporation, Buffalo, N. Y.

Recka, F. A., 254 Linden Street, Waltham, Mass.

Reimann, A. G., 1968 Parker Street, Schenectady, N. Y.

Rosenblatt, J., New York State Department of Labor, Albany.

Schultz, N. R., General Electric Company, Schenectady, N. Y.

Schwennesen, A. B. (Member), New York State Electric and Gas Corporation, Elmira.

Shaw, M. R., Jr., Corning Glass Works, Corning, N. Y.

Shelton, R. B., General Electric Company, Pittsfield, Mass.

Shipp, E. C., General Electric Company, Schenectady, N. Y.

Silliman, M. A., Central New York Power Corporation, Utica, N. Y.

Springer, R. W., Narragansett Electric Company, Providence, R. I.

Tapscott, R. L., General Electric Company, Schenectady, N. Y.

Webb, D. R., General Electric Company, Schenectady, N. Y.

Worthen, C. E., General Radio Company, Cambridge, Mass.

Zelaites, C. A., Narragansett Electric Company, Providence, R. I.

2. MIDDLE EASTERN

Allen, E. H., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Baker, V. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Bliss, M., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Bohn, C. R., Ohio Power Company, Lima.

Bradley, J. K., Westinghouse Electric and Manufacturing Company, Wilkinsburg, Pa.

Brenner, C. H., De Laval Steam Turbine Company, Trenton, N. J.

Brunner, G. J., Cincinnati Gas and Electric Company, Cincinnati, Ohio.

Budny, C. T., United States Navy, Philadelphia, Pa.

Burch, K. E., New Jersey State Highway Department, Trenton.

Calhoun, J. F., Philadelphia Electric Company, Philadelphia, Pa.

Caldwell, D. W., General Electric Company, Cleveland, Ohio.

Campbell, B., Procter and Gamble Company, Ivorydale, Ohio.

Campbell, J., Jr., Bell Telephone Company of Pennsylvania, Philadelphia.

Carl, E. W., Glenn L. Martin Company, Baltimore, Md.

Carpenter, J. W., Rural Electrification Administration, Washington, D. C.

Castonguay, W. R., District of Columbia Highway Department, Washington, D. C.

Charny, A. L. (Member), Bell Telephone Company of Pennsylvania, Philadelphia.

Chase, P. W., Jr., The J. S. Johnson Company, Baltimore, Md.

Chester, P. F., F. R. Hannon Electric Company, Canton, Ohio.

Chyba, H. J., Consolidated Gas, Electric Light and Power Company of Baltimore, Baltimore, Md.

Clautice, B. W., Calvert Distilling Company, Relay, Md.

Davis, L. J., North Electric Manufacturing Company, Galion, Ohio.

DeFuria, P. B., Island Creek Coal Company, Holden, W. Va.

Dennis, F. F., Pennsylvania State College, State College.

Detwiler, J. G. (Member), Central Cable Corporation, Jersey Shore, Pa.

Dorsey, J. R., B. F. Goodrich Company, Akron, Ohio.

Draper, C. A., United Broadcasting Company, Cleveland, Ohio.

Dusenbury, C., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Easley, J. K., General Electric Company, Erie, Pa.

Eidell, R. H., Mack Manufacturing Corporation, Allentown, Pa.

Eichenberg, C. L., Bethlehem Steel Company, Bethlehem, Pa.

Engel, A., United States Navy Yard, Philadelphia, Pa.

Euler, F. J., Jr., Revere Copper and Brass Company, Baltimore, Md.

Evans, F. J., Duquesne Light Company, Pittsburgh, Pa.

Fahrnkopf, C. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Felver, R., Westinghouse Electric and Manufacturing Company, Mansfield, Ohio.

Fink, L., III, Bell Telephone Company of Pennsylvania, Philadelphia.

Frick, G. P., Brown Instrument Company, Philadelphia, Pa.

George, H. T., Edwin L. Wiegand Company, Pittsburgh, Pa.

Giles, W. F., Jr., Gas and Electric Company of Baltimore, Baltimore, Md.

Glass, E. W., General Chemical Company, North Claymont, Del.

Gorman, W. J., American Telephone and Telegraph Company, Philadelphia, Pa.

Gregg, W. E., Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

Guilfoos, L. J., Carnegie Institute of Technology, Pittsburgh, Pa.

Harman, W. W., General Electric Company, Philadelphia, Pa.

Harper, J. A., Apex Hosiery Company, Philadelphia, Pa.

Heigle, W. W., The Ohio Power Company, Portsmouth.

Hendricks, A. W., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Hood, H. C., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Horn, F. C., Lima Electric Motor Company, Lima, Ohio.

Jankiewicz, E. J., Philadelphia Electric Company, Philadelphia, Pa.

Johnson, H. V., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Johnson, L., Jr., Federal Power Commission, Washington, D. C.

Johnston, W. T., The Osborn Manufacturing Company, Cleveland, Ohio.

Jones, J. P., Ohio Edison Company, Springfield.

Kazan, L., care M. Kazan, Philadelphia, Pa.

Kennedy, T. F., Calvert Distilling Company, Relay, Md.

Koch, L. C., R. F. D. 1, Wapakoneta, Ohio.

Landefeld, H., Jr., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.

Lasswell, P. M., United States Air Corps, Wright Field, Dayton, Ohio.
Luce, J. R., Burke Electric Company, Erie, Pa.
Lytle, D. G., United States Chromium Company, Philadelphia, Pa.
Manning, E. C., Rural Electrification Administration, Washington, D. C.
Marx, C. J., Reliance Electric and Engineering Company, Cleveland, Ohio.
Meiklejohn, W. H., General Electric Company Erie, Pa.
Mendelson, S. I., Cleveland Electric Illuminating Company, Cleveland, Ohio.
Metz, L. P., Philadelphia Ordnance District of United States Army, Philadelphia, Pa.
Migdal, S., B. F. Goodrich Company, Akron, Ohio.
Miller, J. W., care John Barron, Washington, D. C.
Mitchell, D. H., Beach Erosion Board, War Department, Washington, D. C.
Monks, W. E., B. W. Cornelius, Consulting Engineer, Columbus, Ohio.
Moore, L. M. (Member), Rural Electrification Administration, Washington, D. C.
Moulton, C. W., Ohio Power Company, Portsmouth.
Nesbit, D. E., Pennsylvania Edison Company, Altoona.
Novak, S. T., Bailey Meter Company, Cleveland, Ohio.
Otterson, L. A., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Otto, W., 2413 Charles Street, N.S., Pittsburgh, Pa.
Parsons, E. H., Rural Electrification Administration, Washington, D. C.
Perry, D. J. (Member), Bell Telephone Company of Pennsylvania, Philadelphia.
Pfister, P. E., The Ohio Power Company, Coshocton.
Quashnock, E. J., Allis-Chalmers Company, Pittsburgh, Pa.
Rathbun, G. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Rea, W., Owens-Illinois Glass Company, Toledo, Ohio.
Renshaw, E. F., Rural Electrification Administration, Washington, D. C.
Rieman, S. T., Columbia Engineering Corporation, Cincinnati, Ohio.
Roehm, L. F., Pennsylvania Electric Company, Johnstown.
Rosenthal, B. R., Raphael Electric Company, Pittsburgh, Pa.
Sandberg, C. E., The Ohio Public Service Company, Ashland.
Sangster, H. L., Potomac Electric Power Company, Washington, D. C.
Schrawder, R. R., Armstrong Cork Company, Lancaster, Pa.
Sieber, F. C., 230 Harris Street, Harrisburg, Pa.
Siefert, W. A., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Slifko, J. P., Babcock and Wilcox Company, Barberton, Ohio.
Smith, S. A., Chesapeake and Potomac Telephone Company, Washington, D. C.
Snyder, R. F., Goodyear Tire and Rubber Company, Akron, Ohio.
Springer, P. W., Columbus and Southern Ohio Electric Company, Athens, Ohio.
Steinkamp, A. T., Department of Public Utilities, City of Cincinnati, Ohio.
Stephens, D. S., Ohio Power Company, Philo.
Strong, R. M., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Swinehart, M. R., B. F. Goodrich Company, Akron, Ohio.
Tarzian, V., 3004 N. Howard Street, Philadelphia, Pa.
Thompson, E. A., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Titus, C. H., Lehigh University, Bethlehem, Pa.
Toben, G. W., Procter and Gamble Company, St. Bernard, Ohio.
Tweeddale, A. L., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Undy, W. W. (Member), E. I. du Pont de Nemours and Company, Deepwater, N. J.
Watson, R. W., Carter Coal Company, Coalwood, W. Va.
Werner, C. J. (Member), General Motors Corporation, Dayton, Ohio.
Wingert, L. E., General Electric Company, Philadelphia, Pa.
Winters, H. M., United States Chromium Corporation, Wilkinsburg, Pa.
Woodard, S. B., General Electric Company, Philadelphia, Pa.
Wurdack, A. C., Jr., Line Material Company, Zanesville, Ohio.
Wurster, J. H., General Electric Company, Erie, Pa.

3. New York City

Adams, R. V., Westinghouse Electric and Manufacturing Company, Newark, N. J.
Allison, H. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Anderson, R. E., Federal Shipbuilding and Drydock Company, Kearny, N. J.
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9 Addresses Wanted

Transactions

Preprint of Papers and Discussions Comprising Pages 193–256 of the 1940 Volume

Methods of Controlling Radio Interference

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ASSOCIATE AIEE

Synopsis: This paper summarizes the recognized methods for reducing at the source man-made radio noises. The effectiveness of the different controlling methods is discussed in the light of efficiency and utility. The use of shunt-type filters and choke coils is so broad that this paper is confined to the more important applications of these controlling devices. Filter methods are so important that specific applications are discussed in detail. The application of these devices to other apparatus is governed by the type, location, and use of the apparatus.

THE PROBLEM of providing satisfactory radio reception to all areas of the United States requires the co-operation and co-ordination of the various industries involved. Improvements in radio service and reduction of radio noise have been made on many fronts. The solution of the problem lies in the mutual co-operation of interested parties, that is, the broadcasters in providing adequate field strength, the radio set manufacturer in supplying equipment and means for installations with minimum practicable susceptibility to unwanted signals, the radio listener in the proper installation and operation of the set, and the manufacturer and user of electrical equipment to see that it is designed and operated so as to produce the minimum of unwanted stray fields. This paper is limited to the latter subject and gives a few of the experiences of manufacturers in the reduction of radio noise from their electrical apparatus.

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Radio receivers are susceptible to two kinds of noise, natural and man-made. Atmospheric noise, more generally called natural static, creates a problem that rests with the makers of the receiver and to some extent with the number, power, location, and type of broadcasting stations. Man-made radio noise, emanating from rotating electrical machines and stationary electrical apparatus, presents not only a problem to the manufacturers but also to those that apply and use the equipment, as the electrical circuit to which the apparatus is connected may have as much influence on the radio noise as the application of a suitable filter or a change in the design of the apparatus. Fortunately, noise from this type of equipment, unlike natural static, is measurable (although not always easily), and is fairly constant in intensity, for a specific piece of equipment.

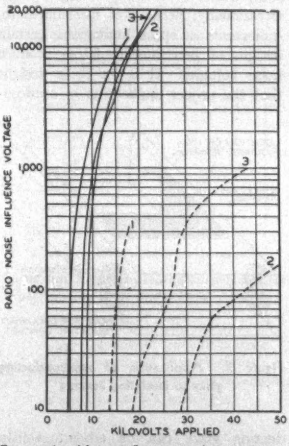

Figure 1. Noise-influence voltage of untreated and treated pin-type insulators

Solid curves—Untreated insulators
Dashed curves—Treated insulators

1—Line voltage 6.9 kv, one piece
2—Line voltage 33.0 kv, one piece
3—Line voltage 33.0 kv, multipart

Both rotating and stationary apparatus are capable of producing radio-noise voltages. The term "radio-noise voltage" will be used hereafter to describe the radio-noise voltage which appears across the input of the radio receiver. This term is used to make a definite distinction between this voltage and the high-frequency voltage measured at the terminals of electrical apparatus when connected to a coupling network. The high-frequency voltage measured at the terminals of electrical apparatus shall hereafter be referred to as the "radio-noise-influence voltage". Commutator and interrupter-type inductor motors are among the rotating apparatus that may produce radio noise while high-voltage line insulators, and to some extent low-voltage porcelain insulators are contributors among non-rotating apparatus.

Methods of Reducing or Eliminating Radio Noise at the Source

Three basic methods of reducing or eliminating apparatus-produced radio noise are recognized and applied with success. They are:

1. Consideration in design
2. Application of low-impedance shunt filters
3. Application of high-impedance series filters

All three methods are not equally effective for a particular device. The method must be suited to the specific source of noise.

Consideration in Design

The possibility of reducing or eliminating the radio-noise-influence voltages in the design of all apparatus is being studied intensively by a large number of manufacturers. All classes of apparatus cannot be economically designed to be noise free but continuous

improvements are being made in many lines. In certain cases the consideration of the noise-influence voltage has resulted in an improvement of the apparatus.

Pin-Type Insulators

In many areas, pin-type insulators on 33- and 66-kv systems are a major source of radio noise on well-designed transmission systems properly constructed and maintained. Radio noise is produced by pin-type insulators as a result of the high voltage gradients across various sections of the insulator. These high voltage gradients are usually across air and other insulation in series. If the gradients are sufficiently high, the air is ionized, allowing a discharge to pass through the air. This discharge is a glow or an arc. In either case, the discharge produces a change in the distributed parameters of the insulator, resulting in the generation of damped transients. It is believed that both ionization and deionization set up damped transients, which appear in connected circuits as noise voltages.

On untreated pin insulators, the principal location of the high voltage gradient is between the line or tie wire and the surface of the insulator. There may also be high voltage gradients across the cement joints between shells, between the pin and the pin hole surface of the porcelain, as well as tangential gradients along the porcelain surfaces of the sheds.

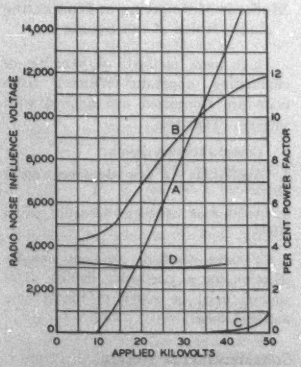

Figure 2. Noise-influence voltage and power-factor of untreated and treated pin-type insulators

A—Noise-influence voltage, untreated insulator
B—Power factor, untreated insulator
C—Noise-influence voltage, treated insulator
D—Power factor, treated insulator

By the proper application of a semiconducting glaze, it is possible to redistribute the voltage to eliminate or reduce the air discharges. The insulators thereupon become free or relatively free of radio-noise voltage as figure 1 shows.

The application of a semiconducting glaze to some pin-type insulators not only reduces the noise-influence voltages but improves the power factor, that is, decreases power loss, as well. The relation between the power factor and the noise-influence voltage of a pin-type insulator is shown by figure 2. The loss, on one of the higher-voltage pin-type insulators, at 40 kv to ground was reduced from 0.98 to 0.38 watt by the application of semiconducting glaze.

Other Porcelain Structures

Studies on a large number of apparatus bushings show that most porcelain structures are free or relatively free of radio noise, at their operating voltage. Occasionally, because of mechanical requirements or space limitations, certain designs of porcelain insulators produce noise voltages. It is on these designs that the proper application of semiconducting glaze can be advantageously applied.

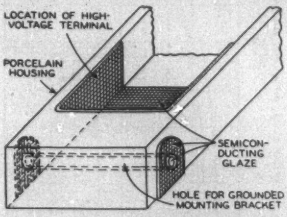

Figure 3. Application of semiconducting glaze to insulating housing

The semiconducting glaze has also been experimentally applied to small porcelain housings, separating outside mounting clamps and inside high-voltage terminals. The proximity of the inside and outside mounting clamps had resulted in high voltage gradients, which produced air discharges at the edges of the clamps along the porcelain surface and between the clamps and the porcelain surface. Upon application of semiconducting glaze to the areas shown in figure 3, the voltage at which noise was detected was increased 100 per cent.

Careful study of insulating structures has indicated that noise voltage can be generated at either the high-voltage or ground terminals or at any intermediate points where the air is overstressed. Partial breakdowns in insulating structures are in general a particularly prolific source of radio noise and can usually be identified by the high values of radio noise accompanying the partial failure.

Figure 4A. Visible corona on a ten-inch untreated suspension insulator at 27 kv

Relation Between Corona and Noise-Influence Voltage

Some power companies are now including in their specifications the requirement that apparatus shall produce no visual corona at operating voltage, with the thought that such a requirement defines the radio-noise characteristics. Tests in the laboratory on a number of types of apparatus has indicated that visual corona is not necessarily a true criterion of the noise-influence voltage, because the method used to decrease the stresses in the visible area may, if the proper precautions are not taken, increase the stresses at other locations where the corona cannot be seen.

This can easily be demonstrated by using asphalt emulsion or similar means to reduce the visual corona between the edge of the cap and the porcelain on a suspension-type insulator. The amount of visual corona produced by a ten-inch suspension insulator at 27 kv to ground before and after the insulator had been treated is shown by figures 4*A* and 4*B*. The noise-influence voltages produced by these two insulators were practically the same.

Electrostatic Shielding

Shielding methods are used on some types of equipment. One of the more common applications of this method outside the radio field is the use of

Figure 48. The ten-inch treated suspension insulator shows no corona at 27 kv

shielding in ignition transformers for oil burners where the spark discharge on the secondary side produces a radio-noise voltage on the primary supply line through the mutual coupling between the primary and secondary windings. The application of shielding does not provide as great a reduction in noise as an external capacitor filter. However, with this type of transformer the application of shielding is more economical than a capacitor filter.

Shielding cannot be applied satisfactorily to all types of transformers because a low-impedance high-frequency ground is difficult to obtain in the general application of this type of equipment.

Experiments and limited application indicate that shielding will find application in eliminating unwanted radiation from various other equipment.

Low-Impedance Shunt Filters

Some apparatus is so constructed that it is impossible to reduce the noise-influence voltage to a satisfactory level through design changes. The application and location of such apparatus will determine whether a filter will be required. The low-impedance shunt filter is generally found to be the most satisfactory for low-voltage applications. Low-impedance shunt filters are simply capacitors of a proper size and rating, suitably connected to reduce the line-to-line and line-to-ground noise-influence voltages. This type of filter finds wide application on commutating machines, and make-and-break devices of various kinds.

The commutating motor produces a noise-influence voltage that has two components that must be separately considered from an interference standpoint. One voltage component is produced between the terminals of the machine, and is commonly referred to as the line-to-line noise-influence voltage. The other voltage component appears between the supply lines jointly as one terminal and ground as the other, and is called the line-to-ground noise-influence voltage.

The noise-influence voltage produced by a commutating machine, is propagated along the supply lines and induces a noise in the radio-receiver antenna by mutual coupling. In general, very little radio-noise voltage is induced in the radio antenna by direct radiation because the field strength around a motor decreases rapidly with increased distance from the machine. The field strength ten feet from a one-fourth-horsepower motor will usually be less than one microvolt per meter.

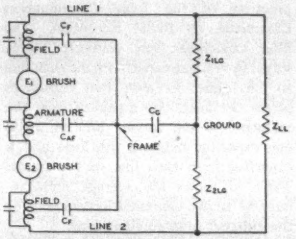

Figure 5. Equivalent circuit of a commutating machine as an interference generator

C_F—Capacity of field to frame
C_{AF}—Capacity of armature to frame
C_G—Capacity of frame to ground
Z_{1LG} and Z_{2LG}—Line-to-ground impedances
Z_{LL}—Line-to-line impedance

An analysis of the equivalent circuit of a commutating machine as an interference generator, figure 5, shows that the voltage from each line to ground, the voltage between lines, and the voltage from frame to ground will be zero if the impedance of each line to the frame of the machine is made zero.

If the impedance of the lines to ground are balanced ($Z_{1LG}=Z_{2LG}$) the voltage from line to ground and frame to ground will not be greatly affected if the line-to-line impedance is made zero. Usually this impedance is not balanced, and some reduction in the line-to-ground voltage is obtained when the line-to-line impedance is decreased. This decrease is insufficient to give adequate noise reduction in most cases. The frame-to-ground voltage is practically unaffected by a reduction in line-to-line impedance under unbalanced line-to-ground impedance conditions.

The closest approach to the ideal condition of zero line-to-frame impedance is obtained with a properly designed shunt capacitance filter. These capacitance filters can be designed to give a minimum impedance over a definite frequency band. Such a filter, designed for one wave band will be less effective in other bands. If maximum protection is desired over a wide frequency band, a number of capacitance filters must be used.

In the United States the filters are nominally designed to give the maximum noise reduction over the broadcast band, which extends from 550 to 1,500 kilocycles. Some apparatus for use elsewhere, however, must be designed to give maximum noise reduction also over the 250 to 400 kilocycle band. Suitable noise reduction in this low-frequency range usually requires larger capacitors for proper filtering.

Commutating motors can be operated either with the frame grounded or ungrounded. When the frame is grounded, maximum noise reduction is obtained by placing capacitors from each line to the frame. The reduction of the noise-influence voltage from a $^1/_{18}$-horsepower motor using two 2.0-, 0.5-, and 0.1- microfarad capacitors over the frequency range 150 to 2,500 kilocycles is shown in table I. The capacitors were connected at *D* and *F*, figure 6, with a total lead length of five inches. The 2.0-microfarad capacitor gives maximum protection in the lower frequency band. The 0.5- and 0.1-microfarad capacitors produce as great a reduction of noise at 1,000 kilocycles and above as does the 2.0-microfarad capacitor. The length of leads used on capacitance filters is important because the lead inductance will tune the ca-

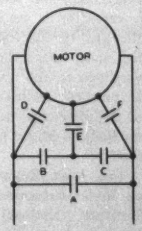

Figure 6. Composite figure showing connection of filter capacitors in vee, wye, and delta

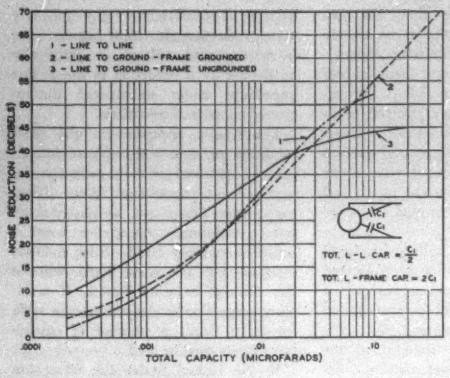
1 - LINE TO LINE
2 - LINE TO GROUND - FRAME GROUNDED
3 - LINE TO GROUND - FRAME UNGROUNDED
NOISE REDUCTION (DECIBELS)
TOTAL CAPACITY (MICROFARADS)
TOT. L-L CAP = C1/2
TOT. L-FRAME CAP = 2C1

Figure 7. Noise-reduction ratios as a function of total filter capacitance

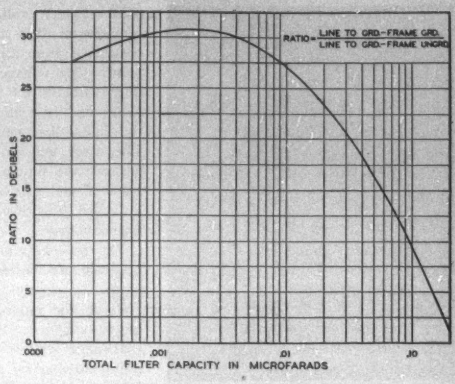

Figure 8. Ratio of line-to-ground noise with the motor frame grounded to the line-to-ground noise with the frame ungrounded as a function of the total filter capacitance

pacitance to series resonance and provide minimum impedance and maximum noise reduction at a definite frequency.

Filters for Ungrounded Device

High-capacitance filters can be used only on grounded-frame machines. Low-capacitance filters to reduce the radio-influence voltage of ungrounded devices such as vacuum sweepers and food mixers must be used to prevent unpleasant shock when they are touched.

If the frame of an unfiltered motor is ungrounded the frame will float at a potential somewhat above ground, depending on the capacity of the windings to the frame and the frame to ground. If the frame is touched no shock will be noticed because of the small capacitance of the windings to the frame. However, when the same motor is filtered, a capacitor is usually connected from the line to the frame. This capacitor has many times the capacitance of the windings to the frame so if the frame is touched, sufficient charging current of the filter capacitor may flow through the body to ground to cause an unpleasant shock.

The Joint Co-ordination Committee on Radio Reception of Edison Electric Institute, National Electrical Manufacturers Association, and Radio Manufacturers Association has recommended that the current to frame of capacitance-type filters be held below 0.3 milliampere. Therefore a filter for an ungrounded device must be designed to give maximum reduction of noise-influence voltage with a limited amount of capacitance.

To show the effects of various size capacitors in filters used for suppressing noise-influence voltages, tests were made on a $^1/_{15}$-horsepower commutating motor. Measurements were made in accordance with the recommended practices of the Joint Co-ordination Committee on Radio Reception. The filter capacitors were connected three ways; in vee, one capacitor from each line to the frame; in wye, two capacitors across the lines, one capacitor from the midpoint to the frame; and in delta, one capacitor between the lines and a capacitor from each line to the frame. Table II shows the average noise reduction ratios, expressed in decibels, for the different filter combinations.

The relation between total capacitance and noise reduction expressed in decibels is shown in figure 7. The abscissa values are in terms of total capacitance line-to-frame or line-to-line and are used with the proper noise-reduction curves. As an example, assume a filter combination of a 0.01-microfarad capacitor connected from each line to the frame. The line-to-line capacitance would be 0.01/2 or 0.005 microfarad and the line-to-frame capacitance would be 2×0.01 or 0.02 microfarad. The 0.005 figure would be used in referring to the line-to-line curve and the 0.02 figure to the line-to-frame curve.

These curves show that with the motor frame ungrounded, little improvement in line-to-ground noise is gained by increasing the capacitance of the line-to-frame capacitor beyond 0.02 microfarad. In general this value will vary with the stray capacitance of the motor to ground as well as the size and type. For the line-to-line and line-to-ground condition with the frame grounded, the improvement increases with increase in capacitor size.

The ratio of line-to-ground noise with the motor frame grounded and ungrounded for various sizes of capacitors is shown in figure 8. To reduce the number of measurements only the vee filter connection was used. The data

Table I. Effect of Capacitor Size in Reducing Radio Noise From $^1/_{15}$-Horsepower Motor

Type of Measurement	Capacitor C_1 (Microfarads)	Reduction of Radio-Noise Output (Decibels)* 200 Kc	340 Kc	600 Kc	1,000 Kc	1,400 Kc	2,000 Kc	2,500 Kc
Line-line	0.1	29.7	33.9	40.5	45.9	41.4	46.7	41.7
	0.5	43.6	49.6	64.8	50.7	39.2	41.8	40.0
	2.0	60.1	54.8	54.8	48.6	38.7	41.2	39.2
Line-ground, frame ungrounded	0.1	36.8	44.0	41.6	37.9	27.2	38.1	37.4
	0.5	41.2	46.7	41.0	37.9	30.4	37.6	37.4
	2.0	40.6	45.2	42.1	39.1	33.5	39.9	39.1
Line-ground, frame grounded	0.1	40.5	47.0	53.0	55.0	44.8	44.8	39.8
	0.5	56.0	62.0	60.6	44.6	43.4	53.4	40.9
	2.0	65.7	77.2	73.7	49.8	49.8	49.2	49.3

* = 20 log (radio-noise voltage unfiltered) / (radio-noise voltage filtered)

Table II

Test	A	B	C	D	E	F	Maximum Filter Current at 120 Volts, 60 Cycles (Milliamperes)	Average Noise Ratio in Decibels, Unfiltered to Filtered: Line-Ground (Grounded)	Line-Ground (Ungrounded)	Line-Line*
1	0.05						0	0	0	46.9
2				0.0001		0.0001	0.005	4.6	9.8	0
3				0.0005		0.0005	0.023	11.4	19.4	3
4				0.001		0.001	0.045	15.7	24	6.7
5				0.003		0.003	0.135	24.4	31.2	12.7
6				0.006		0.006	0.27	32.6	36.2	16.8
7				0.01		0.01	0.45	37	40	24.2
8				0.05		0.05	2.25	55.7	44	43
9				0.10		0.10	4.5	63	45	48.5
10				0.2		9	69.1	40	52.2	
11	0.05			0.003		0.003	0.27	26	31.2	46
12	0.05			0.006		0.006	0.54	32	37.1	46.8
13	0.05			0.01		0.01	0.91	36.5	40	46.8
14	0.01			0.003		0.003	0.27	25.7	31.2	33.3
15	0.01			0.006		0.006	0.54	31.7	37.1	33.3
16		0.01	0.01		0.006		0.21	23	29.4	26.7
17		0.01	0.01		0.01		0.30	27.7	32.7	26.4
18		0.10	0.10		0.003		0.13	17.8	25.4	46.2
19		0.10	0.10		0.006		0.26	24.8	31.2	46.2
20		0.10	0.10		0.01		0.43	51.4	41.5	46.2

* There was no substantial change in the line-line noise with frame grounded or ungrounded.

shows that for the smaller sizes of filter capacitors the radio-noise voltage to ground is increased by grounding the frame while for the larger sizes of capacitors, the noise voltage is decreased by grounding the frame.

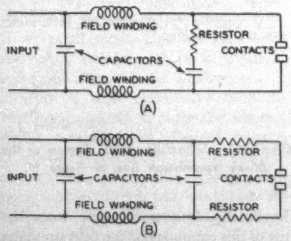

Figure 9. Filter circuits for interrupter-type inductor motors

Figure 10. Noise measurement along a 66-kv transmission line showing the effect of reflections

It should be noted that these data indicate results on a particular motor and while it is indicative of the performance of commutating motors, the conclusions should not be generally applied to all apparatus.

Make-and-Break Contacts

Apparatus in which electrical contact is made and broken frequently is the source of an annoying form of interference. Make-and-break circuits are usually filtered with a resistance and capacitance combination. The amount of capacitance across the contacts is important from the standpoint of life of the contacts and the reduction of noise-influence voltage. The resistance properly placed in the circuit, performs two functions; it limits the short-circuit current of the capacitor, and it acts as an internal impedance in the noise-voltage circuit. A combination of capacitance and resistance can usually be chosen to achieve the desired noise reduction.

The interrupter-type motor is an example of this form of noise generator. This motor depends for its operation on a properly synchronized make and break of the current flowing in the field coils.

Capacitance is usually connected across the make and break contacts of the motor to reduce arcing and heating of the contacts. This capacitance must be kept sufficiently low that the contacts will not weld and cause sticking when the capacitance is short-circuited by the contacts. The capacitance that is generally used for this purpose is not sufficient to reduce the noise value to a satisfactory level. The application of larger capacitance requires the addition of resistance to reduce the capacitor discharge when the contacts close. Two resistance and capacitance combinations which are satisfactory for this type of application are shown by figure 9. The combination shown by figure 9*B* has been used to reduce the noise voltage of an electric razor to less than 0.5 per cent of its original value.

The circuit shown by figure 9*A* does not give the reduction of figure 9*B* on this type of make-and-break circuit, but is applicable where resistance cannot be placed in series with the line.

High-Impedance Filters

Radio-Frequency Choke Coils

When high-voltage apparatus is considered, the cost of shunt-type filters becomes uneconomical and high-impedance series filters must be applied. These filters take the form of tuned choke coils and find application on high-voltage transmission lines, telephone lines, and distribution networks. They are not usually used to reduce radio

Figure 11. Noise measurements along a 66-kv transmission line showing the effect of parallel lines

A—Line normal
B—Telephone choke short-circuited
C—Line dead at pole 5-39

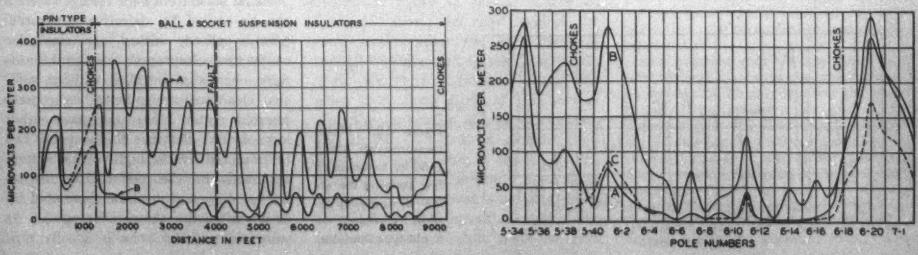

Table III

Test Number	Description of Tests	Noise Starting Voltage (Kilovolts)
1	Standard 6.9-kv insulator on wood cross arm with wood pin	19.8
2	Standard 6.9-kv insulator on wood cross arm with metal pin. Pin not grounded	7.7
3	Standard 6.9-kv insulator on wood cross arm with metal pin. Pin grounded	4.9
4	Standard 6.9-kv insulator on metal pole-top pin. Pin not grounded. Guy-wire hook and lag bolt close to pin grounded	5.6
5	Standard 6.9-kv insulator on metal pole-top pin. Pin not grounded. Grounded guy-wire hook and lag bolt removed	5.75
6	Standard 6.9-kv insulator on metal pole-top pin. Pin grounded	4.9
7	Treated 6.9-kv insulator on pole-top pin. Pin not grounded. Guy-wire hook and lag bolt close to pin grounded	21.3
8	Treated 6.9-kv insulator on wood cross arm with metal pin. Pin not grounded	13.8
9	Treated 6.9-kv insulator on wood cross arm with metal pin. Pin grounded	20.25
10	Treated 6.9-kv insulator on wood cross arm with cross arm brace grounded. Pin not grounded	10.75

noise at the source but are used to attenuate the transmission of noise from specific sections of the circuit.

Field experience has demonstrated the radio-frequency choke coils can be applied to transmission lines and give satisfactory performance provided they are applied properly. One of the most common mistakes made in their application is attempting to sectionalize a part of a line without completely eliminating the radio noise in the section. When noise is generated in the sectionalized part of the line, the radio-frequency noise is reflected at the choke coils. This noise may be amplified a number of times, depending upon the distance between the chokes.

An example of such a situation is illustrated by figure 10 curve *B* indicates the noise field strength measured along a reinsulated section of a 66-kv pin-type transmission line. The section was reinsulated with suspension insulators. Choke coils were installed at each end of the reinsulated section.

After the line had been in service for several years, a line fault occurred which resulted in numerous radio complaints. The line was again surveyed and field strengths as shown by curve *A*, figure 10, were obtained. Normally a high noise level is obtained at the pole where the fault occurs, however, it may be seen by referring to curve *A*, that noise peaks occurred all along the major portion of the reinsulated section. Several unsuccessful attempts were made in an effort to locate the fault. As a last resort, the chokes were short-circuited and the fault was readily located at the point indicated on figure 10. After the fault had been corrected, the choke coils were again inserted in the line and the noise returned to its original level.

It should be noted that the noise peaks occur approximately every 450 feet, which is a half wave length of 1,090 kilocycles. This is exactly the frequency of measurement indicating reflections from the choke coils.

This same effect is obtained when a reinsulated section is not entirely free of radio noise. A number of radio-frequency choke-coil installations have been declared unsuccessful due to insufficient reduction of noise. These unsatisfactory choke-coil installations have in general been caused by the lack of proper reinsulation in the desired sections. If reflections are present in an apparently unsuccessful choke-coil application, a complete inspection of the reinsulated section should be made.

The proper application of radio-frequency choke coils requires that they be inserted in all parallel lines. The radio-noise field strength produced by a 66-kv line with a paralleling telephone line on the same poles, after it had been reinsulated and choke coils inserted in both the 66-kv line and telephone line, is shown by curve *A* of figure 11.

During a storm one of the telephone choke coils was destroyed by lightning and a resurvey of the line indicated a noise level as shown by curve *B*. After the insertion of a new telephone choke coil, the noise level again was reduced to that shown by curve *A*. The noise level of this line when the line was open at pole 5-39 and energized from the other end is shown by curve *C*.

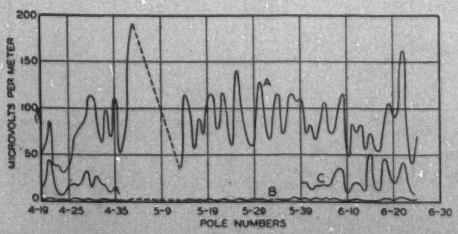

Figure 12. Noise measurements along a 66-kv transmission line showing the effect of applying asphalt emulsion to pin-type insulators

Field Investigations of Noise From Transmission-Line Equipment

In certain areas an important source of radio interference produced by electric-power-system apparatus is from high-voltage transmission lines. In general its importance arises not so much from its severity as from the fact that it may be continuously present. The situation is aggravated by the fact that such equipment is located in areas of low broadcasting field strengths.

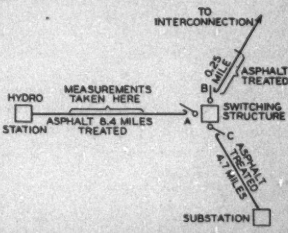

Figure 13. Schematic switch diagram of the 66-kv transmission line of figure 12

Less complaints would arise from the use of this equipment if the field strengths that are available during evening and night hours, were available during the day. Usually the daytime field strengths are from one to ten per cent of the evening and night field strengths, and as a result complaints are received even with low levels of radio-noise voltage.

Radio noise from high-voltage systems can be caused by defective apparatus; poorly spliced, nicked, or small-size conductors; improperly designed hardware; hardware installed without sufficient clearance; arcing horns; improperly inserted cotter pins, and many other less obvious details. Radio noise can be produced by the high-voltage system apparatus in the performance of its normal duty and must be eliminated by design after the cause is detected. At substations, radio noise is usually pro-

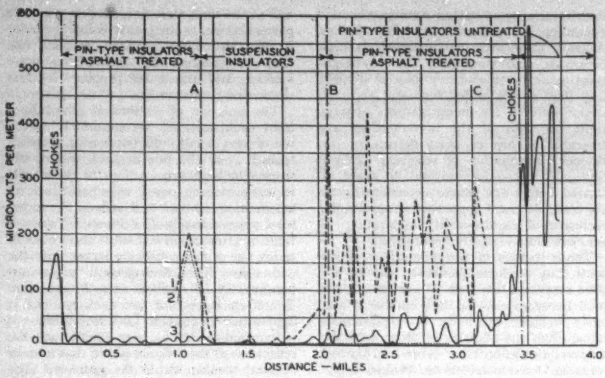

Figure 14. Noise measurements along a 66-kv transmission line with different types of reinsulation

duced by certain types of apparatus whose limitations in this respect must be recognized and allowed for.

Rural Lines

It is generally believed that insulators on 11.8-kv rural transmission lines do not produce radio interference. Where wood pins are used this is usually true. However, if metal pins are used with standard insulators, there is considerable possibility of radio interference. A number of such cases have been investigated and one in particular where a power company had changed from a cross-arm construction to a pole-top construction. After the change had been completed, this line, previously interference free, became the cause of many radio complaints.

To check this condition, a pole which had been standing in the open for several years, was brought into the laboratory and arranged so that the cross arm, pole-top pin, guy-wire hook, and lag bolts were mounted exactly according to the public-utilities specifications. The results of these tests are shown in table III.

The insulator on the wooden pin did not create any noise below 19.8 kv. This same insulator with a grounded metal pin started to create noise at 4.9 kv, as measured by the circuit adopted by the joint co-ordination committee of EEI, NEMA, and RMA on radio reception. This insulator mounted on the pole-top pin started to produce noise at 5.6 kv. With the guy-wire hook and lag bolt removed from the pole, this insulator still started to produce noise at 5.75 kv.

Tests 8, 9, and 10 are interesting because they show that under actual field conditions the starting noise voltage can be lower when the pin is ungrounded, because of the leakage current flowing from the metal pin to the cross arm or from the cross arm to a grounded cross-arm brace.

Test 7, indicated that it would be necessary to use radio-interference-proof insulator on the pole-top pin if interference was to be eliminated. This procedure was adopted by one power company. Another company transferred to a wooden pin mounted on a metal bracket.

Application of Asphalt Emulsion

Asphalt emulsion has been used successfully in many applications to reduce the radio noise produced by high-voltage pin-type insulators. The effect of such an application on an actual line is shown by figure 12. The treated line, switching stations, and the point where the measurements were made are schematically shown in figure 13. Curve *A* of figure 12 shows the noise level of a section of this line before application of the asphalt emulsion with all switches indicated in figure 13 closed. Curve *B*, figure 12, shows the noise level of the same section after the application of asphalt emulsion and switch *C*, figure 13, open. Curve *C*, figure 12 shows the noise level along parts of this section after the application of asphalt emulsion and switch *C*, figure 13, closed. Considerable radio noise is shown coming from the untreated section. Also, figure 12 shows that the noise is not attenuated as rapidly as is frequently assumed because the measurement made at pole 4-19 is approximately five miles from switch *C*. Choke coils should be inserted between switch *C* and the untreated section for maximum effectiveness.

The reduction in radio noise from another line with the application of asphalt emulsion is shown in figure 14. This line was a 66-kv pin-type transmission line mounted on wood poles.

The first attempt at reducing the radio noise along a section of this line consisted of reinsulating the section between *A* and *B* with suspension insulators, treating the pin-type insulators from point *B* to point *C* with asphalt emulsion, and inserting radio-frequency choke coils at *A* and *B*. The noise along this line with this construction is shown by curve 1, figure 14.

This installation did not protect sufficient area and tests were conducted to determine the noise level of asphalt-treated section by cutting the line at point *C* and energizing the line from the other end. The noise level under the asphalt-treated section (*B* to *C*) then became very low, as indicated by curve 2, figure 14.

The line was reinsulated as shown by figure 14, and the choke coils moved to their final position as shown. The noise level over the entire area is shown by curve 3, figure 16.

The results shown by these curves demonstrate that:

1. Asphalt emulsion, when properly applied, is fairly effective in reducing inherent pin-type insulator noise.

2. Suspension insulators provide the lowest noise level.

3. Radio noise travels for a considerable distance along the line conductors making the use of radio-frequency choke coils necessary in order to avoid the replacement or treatment of an excessive number of insulators.

Discussion

Charles J. Miller, Jr. (The Ohio Brass Company, Barberton): Mr. Aggers has summarized quite clearly some of the principles that may be applied to control radio interference.

In connection with the application of a semiconducting glaze to pin-type insulators he states that its use improves the power factor of the insulator. He gives no explanation as to why the losses are reduced. In the case of the ordinary insulator, the corona discharge at the tie wire and conductor, and at other parts of the insulator if it exists, requires a small but definite amount of energy to produce it. This represents an energy loss in excess of that occurring within the porcelain itself. With

the application of a semiconducting glaze which effectively suppresses the formation of corona, the total losses of the insulator are reduced and accordingly the power factor is improved.

The electrostatic capacitance of the treated unit is usually somewhat greater than that of an untreated unit, and if the inherent losses in the porcelain are equal in each insulator, the power factor of the treated unit will be smaller than that of the untreated unit. However, it is probably the suppression of the corona discharge that contributes the greater share to the lower power factor of the treated insulator.

The comments on the relation between corona and noise-influence voltage are very interesting and confirm many similar observations made at the Barberton laboratory of the Ohio Brass Company. For example, tests on three-unit strings of suspension insulators have shown wide variations between the visual corona point and the radio-influence voltages. On two similar strings the lowest visual corona point detectable corresponded to a radio influence voltage of 5 microvolts in one case and 50 microvolts in the other.

The use of radio-frequency choke coils in connection with high-voltage transmission lines to isolate or block out the interference from a given protected area is a well-known principle. The use of tuned choke coils in series with every conductor at the point of installation will provide a very effective blockade for a given band of frequencies centered on the resonant frequency of the choke. It has been customary to tune these coils at a frequency somewhere near the middle of the broadcast band. In special cases the coils may be tuned to suppress any particular band of frequencies. However, the use of all-wave receivers now makes it desirable to provide wide-band suppression. A statement of how wide a band of frequencies may be satisfactorily suppressed by the use of tuned choke coils and what provisions could be made for wide-band suppression would be appreciated.

The application of asphalt emulsion for the suppression of radio noise from pin-type insulators has been used for a number of years. However, it is generally conceded that the treatment is not permanent as it tends to deteriorate after a few years. It would be interesting to know the life of the asphalt treatment on the transmission lines discussed by Mr. Aggers in this paper.

W. F. Grimes (Radio Interference Engineering Bureau, Inc., Los Angeles, Calif.): C. V. Aggers in his paper presents a number of methods for controlling radio noise originating under specified conditions. The suppression methods described have all demonstrated their efficiency under actual operating conditions and they are in everyday use. The title of the paper has been well chosen, suggesting as it does additions to existing equipment for the sole purpose of improving radio reception.

It may be of interest to consider, briefly, the conditions under which controlling methods must be applied and the relation of these conditions to other circumstances under which the radio listener has been found to be not satisfied with radio reception. The data to be considered are based on the experience of the co-operative radio-interference investigating agency which is operating in and near the city of Los Angeles, in an area of comparatively high broadcast field strengths. The investigations made by this agency may be divided into four groups which represent separate responsibilities for investigation. Forty-eight per cent of the investigations are traceable to one or more defects in the listener's installation or receiver; 24 per cent, either too intermittent to trace or cleared before the source determined; 20 per cent, electrical apparatus or appliances, exclusive of electric-utility apparatus; 8 per cent, electric-utility apparatus.

Those sources of interference to which controlling methods should or may be applied represent less than 20 per cent of the total investigated. Of this number a majority require servicing or replacement rather than the addition of filters or other suppression equipment. Worn and burned contacts, loose connections, broken bushings, and similar sources of interference should be repaired or replaced.

Nearly 50 per cent of the radio listeners who report interference do so because they lack understanding of the problem or have not been properly advised. These individuals believe their trouble is due to interference when actually it is due to a defective receiver or lack of correct receiver installation.

These remarks are intended only to point out that in order to develop maximum use of radio-receiving equipment it is necessary to consider all of the factors disturbing to the listener. Methods of controlling radio interference must eventually be applied to apparatus, when required, at the point of manufacture. The radio and electrical industries are urged to consider the general problems of the listener and to initiate an active co-operative campaign designed to develop listener interest and understanding.

A. M. Lane (representing General Electric Supply Corporation and Locke Insulator Corporation, San Francisco, Calif.): Mr. Aggers has presented a very interesting paper. These remarks are with reference to that part of his paper dealing with radio-frequency choke coils and are somewhat supplementary. Possibly a brief description of radio-frequency attenuation coils for wire lines would be of interest.

Radio noise caused at any point on a power system travels along the wires with very little attenuation, thus producing interference for many miles. To prevent all interference at a certain location, it has been necessary in the past to clear up all noise sources for many miles in all directions along the wires. Experience has shown this to be extremely difficult and expensive, and the job is never finished because new sources of noise are continually forming.

Fortunately, radio noise is objectionable only at certain sections of most power lines, such as in thickly settled districts or near radio-receiving stations. In the course of our investigations we found that the Radio Interference Specialty Company had developed a practical method which prevents radio noise of all frequencies from passing a given point in a power line. Thus, a section of line where noise is objectionable can be isolated from the rest of the power system with regard to radio-frequency noise and at the same time not interfere with the power service, or the transmission of carrier frequencies. These isolated sections can then be economically freed from noise sources, and the noise problem is thus eliminated permanently.

The isolation of sections of power lines from radio noise is accomplished by the use of very small inductance coils properly spaced along the line at each end of the section to be isolated. Two of these coils in series in each power wire constitute an attenuation section and reduce the noise level approximately 25 decibels. Two sections of attenuation consist of three coils in series, the center coil being larger than the end coils. This arrangement gives approximately 50 decibels noise attenuation. The 60-cycle loss for two such sections is approximately equal to 1,200 feet of line.

In practice, it has been found that the reflections at the coils are so low that sources of local trouble within the protected area may be readily located.

The spacing between coils is important and depends upon the electrical constants of the power line and the lowest frequency it is desired to stop. However, the spacing can always be arranged so that the coils can be mounted on existing poles. The coils should always be installed where there are the least number of paralleling wires such as telephone lines and secondaries, as these lines pick up and carry the radio noise. All coils are fitted with spark gaps as a protection against lightning and have been tested with artificial lightning of 2,000,000 volts.

Attenuation coils meeting the requirements of the telephone and telegraph companies have been developed for installation on open-wire lines, even though such lines must accommodate telephone and telegraph carrier channels.

One of the earliest of the many existing installations was made for the protection of the radio-receiving station of the Mackay Radio Telegraph Company located about 40 miles south of San Francisco near the ocean. In this installation coils were placed in the 11-kv power wires and the telephone toll wires. This installation has thoroughly protected all frequencies for the radio company's world-wide receivers since the first part of 1933.

Measurements of the amount of reduction in interference have been made by the telephone company and several power companies. These measurements show that a reduction of 98 per cent in the radio noise may be obtained over the frequency band from 500 kilocycles to 14 megacycles. It is probable that the protection extends to much higher frequencies, although no such measurements have yet been made.

R. J. Sullivan (Commonwealth and Southern Corporation, Jackson, Mich.): This paper is a valuable contribution to the literature on the subject of radio interference. This is a field of investigation in which much remains to be accomplished, and in which a comparatively small amount of published information is available. No doubt many independent investigations have been carried on, the results of which have not been published, perhaps partly because more or less makeshift apparatus was used which did not permit the results to be published in the quantitative form

of curves and tabulations which are usually considered to be requisites of successful technical papers. This situation will be improved if the standard test circuit recommended by the Joint Co-ordination Committee on Radio Reception becomes widely used in such investigations.

The section of the paper dealing with radio interference produced by electric-power-system apparatus invites further discussion. The statement that radio noise produced by high-voltage system apparatus ". . . must be eliminated by design after the cause is detected", is part of the story; and the statement that "radio noise from high-voltage systems can be caused by defective apparatus," is another part. Improvements in design will not eliminate individual cases of interference due to defective materials or poor workmanship. In either case if the noise-radiating equipment is allowed to get into service it may cause considerable irritation and expense to its purchaser before being identified as a source of radio interference. This paper offers useful information on dealing with equipment already in service, but it would be very interesting to know what is being done by the manufacturers in the way of production testing of equipment for radio interference before it leaves the factory. This would be considered as an important part of the test procedure by those members of the operating organizations who have the job of investigating radio-interference complaints.

It is not clear what is meant by "high-voltage systems". Severe interference can be caused by defective distribution apparatus of voltages at least as low as 6,900 volts. Interference has been found to originate in distribution transformers in the high-voltage bushings, high-voltage leads and taps which are not spaced sufficiently, defective insulation which would withstand the usual high-potential insulation tests, and other defects, such as carbonized terminal blocks. One investigation disclosed a batch of new 7,200-volt distribution transformers which caused a very high level of radio interference due to the fact that they had been overbaked during the impregnation process at the factory which raised blisters in the insulation between the high-voltage and low-voltage windings. The potential gradient across the insulation produced a glow discharge in these voids which started at less than half rated voltage. The overbaking also left the insulation in a brittle condition, but the defect was only detected by the radio-interference test, which could have served the same purpose during a factory test.

A considerable range of starting voltages for radio interference has been found for transformer bushings filled with asphalt compounds, above 7,200 volts, due to voids in the compound. This characteristic is subject to control in the manufacturing process if it is taken into consideration. Many of the offending bushings are old types, of which large numbers are still in service and still being manufactured for replacements.

In connection with the treatment of insulators to reduce radio noise, a discussion of the following points should be of interest:

What variations can be expected in the radio-interference starting voltages of a number of semiconducting glaze insulators of the same design with respect to rated voltage?

What effect does dirt have on the radio-interference qualities of treated insulators?

How long can asphalt emulsion be expected to act as a radio-noise-reducing agent when exposed to normal weather conditions?

C. V. Aggers: Mr. Lane has presented a very interesting discussion on the radio-frequency attenuation coils which have been used to isolate sections of telephone and power lines. These coils are apparently designed so as to provide a single- or two-section T-type low-pass filter in which the capacity of the conductors to ground is used as the capacitance element of the filter.

This method of isolation should, and apparently does provide adequate protection over a very wide frequency range provided the precautions enumerated by Mr. Lane are adhered to.

Mr. Miller has explained why the losses are reduced by the application of semi-conducting glazes. However, if the proper precautions are not taken, it is possible to increase the inherent loss of an insulator to such a value that these losses may exceed the reduction obtained by the elimination of the corona discharges.

Mr. Miller pointed out that the use of all-wave receivers now makes it desirable to provide wide-band suppression. In general, the present type of chokes are designed to provide protection in the broadcast band, 550 to 1,500 kilocycles. Choke coils to provide protection over a wider band have not, in general, been found necessary up to the present time. If and when wider-band-spread protection is desired, the method discussed by Mr. Lane will probably offer the most economical solution.

Chokes for other applications have been designed for wider band spreads. One application required a coil that had a minimum impedance of 10,000 ohms from 300 to 3,000 kilocycles.

Mr. Miller requested the life of the asphalt treatment on the transmission lines discussed. These lines were inspected by the power company after approximately five years of service and it was felt, at that time, that they could reasonably expect a life of ten years from this treatment. The life of this treatment, of course, varies with the precautions taken during its application as well as the climatic conditions.

Mr. Sullivan desires to know what is being done by manufacturers in the production testing of equipment radio interference before it leaves the factory. At least one company is testing all treated insulators before shipment. Other companies are considering the same procedure. In general, radio interference is considered in the development of the certain type of equipment and tests conducted on the first production lots. If these units are satisfactory then sample lots are checked at various intervals.

It is realized that severe interference can be produced by 6,900-volt equipment. In general, the term high-voltage systems has been applied to voltages above 1,000 volts in order to distinguish this equipment for the equipment that operates from the distribution secondaries.

Referring to Mr. Sullivan's question regarding the variation that can be expected in the ratio-interference starting voltage of a number of semiconducting-glaze insulators of the same design, no one has been able definitely to define starting voltage. We have not attacked the problem from this angle because some insulators produce a measurable amount of noise voltage at what you might call its starting voltage. On other insulators the voltage may vary five to ten kilovolts between the point of first detection of noise by a headset and the point where the unit produces a measurable value (in the order of 10 or 20 microvolts). However, if a definite number of microvolts is used to define the starting voltage, there may be considerable variation in the starting voltage. This variation will depend upon the type of treatment used on the insulator and the method of applying the test voltage.

The general method of attack has been to measure the noise at various voltages and plot an envelope curve. This curve gives the variation which can be expected in any one design and the maximum value must be below any noise voltage which may be considered for standardization.

The type of data described above is for use only by the design engineer as the operating engineer is only interested in the noise voltage at the operating voltage which after all is the criterion as to whether an insulator will be a cause of radio-interference complaint.

The insulator manufacturers in general are attempting to establish a definite number of microvolts for a particular voltage classification. The values which they are considering are sufficiently low to prohibit any possibility of a noise complaint from this equipment.

Experience in the field to date has indicated that dirt has little or no effect on the radio-interference qualities of a treated unit. Experience in the laboratories has indicated the characteristics are changed slightly; these changes have generally indicated an improvement of its characteristics but not sufficient to warrant any noticeable change in line noise.

Information in regard to the expected life of asphalt emulsion is covered in my reply to Mr. Miller.

Mr. Grimes pointed out in his discussion some of the other factors that must be considered and remedied before satisfactory radio reception can be obtained by all listeners. As pointed out in the paper, the ultimate solution of this problem requires the co-operative efforts of the radio listeners as well as all the involved industries.

"Magne-Blast" Air Circuit Breaker for 5,000-Volt Service

E. W. BOEHNE
MEMBER AIEE

L. J. LINDE
ASSOCIATE AIEE

Synopsis: Fundamental principles of magnetic action and thermal reaction have been united in an original manner to create a new circuit interrupter, the "Magne-Blast" air circuit breaker. Intended for general applications in switching, controlling, and protecting 2,300- to 5,000-volt circuits, this breaker, throughout a comprehensive test program, has proved satisfactory in every requirement. An open presentation of test results shows how an efficient arc chute functions thermally to decay and extinguish the arc with a minimum of voltage disturbance. The breaker is immune to circuit recovery characteristics.

Principles of performance are discussed using the familiar terms of current, voltage, resistance, and reactance in showing their effect on the instantaneous values of phase angle, current reduction, and the attendant rates of rise of recovery voltage. The coordinated electrical and mechanical design is described in some detail and a typical arrangement is shown as used in a metal-clad equipment.

Background

OIL circuit breakers have a history beginning with the early application of alternating currents in the electrical power industry. Throughout this period, oil breakers have maintained a satisfactory record of performance. Failures have been rare, maintenance low, and it has been possible to build circuit breakers of all ratings. Although oil, by its presence alone, constitutes a hazard from leakage or fire, operating engineers will seldom sacrifice any of the proved advantages of modern oil circuit breakers to eliminate the rather remote hazard of fire. But, when freedom from oil is added to all the good points, an oilless breaker becomes attractive. The magnetic air breaker, though long used on d-c systems, has been of minor importance in the intermediate-voltage circuits of the utilities.

To be completely successful in competing with an oil circuit breaker, an air circuit breaker cannot afford to be its inferior in any respect. Available field experience permits a ready review of conventional air breaker performance, for manufacturers have long succeeded in maintaining the position of such breakers in the railway and industrial fields. This experience has proved these magnetic breakers handicapped in their appeal to the utilities only because of their:

1. Poor space factor.
2. Exposed flame, demanding careful segregation.
3. Visual and audible disturbance.

These same breakers, however, provide an argument to their favor in an acknowledged record for:

1. Positive circuit control.
2. Little deterioration of materials during interruption.
3. Economical operating life.
4. Simple contacts and arc-interrupting details.

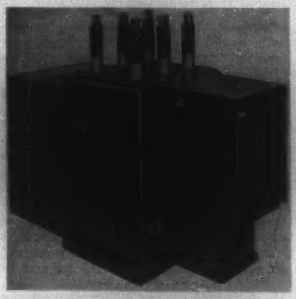

Figure 1. A left-front view of a 1,200-ampere Magne-Blast air circuit breaker for use on 2,300- to 5,000-volt circuits

Insulated for 7.5 kv, rated interrupting capacity 100,000 kva. This breaker is arranged for use in a vertical-lift metal-clad equipment

Though boasting of the obvious advantages here listed, magnetic air breakers have been forced to a secondary position by the problems of size, flame, and disturbance. The "Magne-Blast" circuit breaker offers a solution to these problems while maintaining every advantage of previous breakers.

Application

Unless custom-built to meet the requirements of a particular application, the value of a power circuit breaker is enhanced by the variety of applications it will satisfactorily meet. The breadth of this field is responsible for the variety of characteristics that are today demanded of breakers. Fortunately these characteristics may be grouped into three classes: switching, protection, and control; each making its individual demands on equipment.

Listed below are the most important characteristics of a good breaker:

1. Reliable circuit interruption.
2. High insulation level.
3. Long and economical operating life.
4. Little hazard and disturbance.
5. Small size.
6. High operating speed.

The air circuit breaker here described meets every objective listed.

Under the heading of performance will

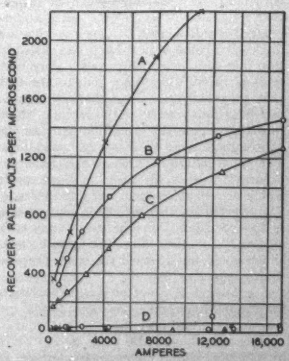

Figure 2. The influence of the Magne-Blast air circuit breaker on the voltage-recovery characteristics of typical circuits

A, B, and *C*—Characteristic rates of rise of recovery voltage for three test circuits

D—Rates of rise of recovery voltage of the same circuits during Magne-Blast circuit-breaker tests

These data were recorded with a cathode-ray oscillograph

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E. W. Boehne is research engineer and L. J. Linde is design engineer, General Electric Company, Philadelphia, Pa.

Reliance has been placed on the co-operative efforts of many individuals during the successful development of the Magne-Blast air circuit breaker. Appreciation is expressed for the valuable contributions from the staffs of the circuit-breaker test laboratory and the research laboratory of the General Electric Company. The Philadelphia Electric Company and the Aluminum Company of America are credited with the original applications of this breaker to their systems, thus providing initial service experience.

be found a rather thorough presentation of the interrupting ability of the breaker. The device exhibits no fire throughout the limits of its interrupting rating. This, together with desirable space factors permitted by an efficient arrangement of materials, has enabled the breaker to be applied in standard vertical-lift metal-clad gear. Here the two enhance each other, the gear providing all its many advantages of safety, installation costs, and appearance; the breaker providing safe and reliable circuit control.

The long operating life of the air device makes it particularly attractive in services where duty demands frequent operation. In fact, the air breaker makes certain industrial functional operations less complicated. For example, present - day furnace operators have learned by experience that if the breaker current is reduced before the breaker is operated, oil deterioration is reduced. This process is recommended at the sacrifice of the time to raise the furnace electrodes. The air device simplifies these industrial functions.

An exceedingly attractive feature of the new breaker is its immunity to circuit recovery characteristics. This desirable characteristic is achieved by the "Magne-Blast" arc-resistance characteristic which, in spite of the inductive properties of the circuit, holds the recovery rate and peak recovery voltage to a value which is only a weak counterpart of the circuit characteristic. These features are described in figure 2 and will be discussed later in detail. In brief, this characteristic of the breaker broadens its field of application, particularly where sudden switching surges endanger associated equipment.

Taken as a whole, this oilless device, incorporating all the sturdiness and reliability of the oil breaker, together with the attendant ease of circuit interruption, space considerations, and maintenance, offers to the industry a new interrupter which should find a wide field of practical applications.

Performance

Of all power equipment, the breaker has to meet the most unusual conditions. It must function unerringly to divorce the energy source from the circuit in distress and still function as the energy valve under all normal conditions. In addition to its protective values, the breaker may be utilized as a switching device accumulating many thousands of operations throughout the year. These, and other requirements, demand that the power breaker perform as a compact, sturdy, and co-ordinated application of mechanical and electrical principles.

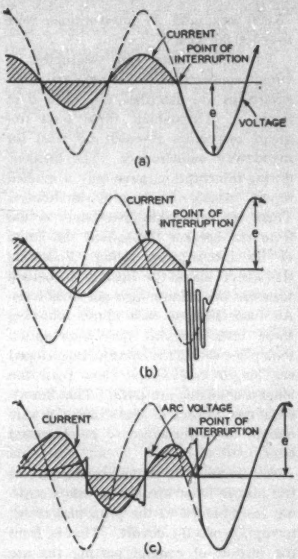

Figure 3

(a)—A typical interruption on a unity-power-factor circuit where the current and voltage zeros coincide

(b)—A typical interruption on a zero-power-factor circuit. Interruption occurs at a current zero with recovery voltage at a peak, thereby encouraging high-frequency transients and a high recovery rate

(c)—A Magne-Blast interruption of a zero-power-factor circuit illustrating the effect of arc resistance in shifting the current zero toward voltage zeros to reduce the rate of voltage recovery

Table I. Interrupting Tests on 600-Ampere Indoor-Type Magne-Blast Air Circuit Breaker

Interrupting Rating—100,000 Kva at 5,000 Volts, Three Phase

Volts	Operation†	Test Frequency	Current (Amperes) Maximum Peak	Current (Amperes) Initial in Arc (RMS)	Three Phase Kva	Arc Duration (Cycles)	Interrupting Time* (Cycles)
2,300	O	60	690	330	1,320	5.5	9.5
2,300	O	60	1,230	660	2,600	3.0	7.5
2,300	O	60	2,600	1,150	4,600	2.0	6.8
2,300	O	60	4,000	1,870	7,500	1.7	6.3
2,300	O	60	14,500	6,200	25,000	1.0	6.5
2,300	O	60	25,000	9,000	38,000	0.8	5.0
2,300	O	60	45,000	16,800	67,000	0.7	4.8
2,300	O	60	71,000	25,000	100,000	1.0	4.3
2,300	CO	60	700	340	1,350	4.5	9.3
2,300	CO	60	1,310	710	2,800	3.3	8.0
2,300	CO	60	2,500	1,090	4,400	2.0	6.5
2,300	CO	60	4,900	2,700	10,800	1.6	6.3
2,300	CO	60	8,500	4,000	16,000	1.3	6.5
2,300	CO	60	13,300	6,700	27,000	0.9	6.0
2,300	CO	60	23,000	9,200	37,000	0.7	4.8
2,300	CO	60	45,000	19,300	77,000	0.7	5.5
2,500	CO	60	72,000	24,000	103,000	0.7	5.0
3,000	O	60	79,000	33,000	171,000	0.6	3.8
4,500	O	60	1,280	690	5,400	3.3	7.3
4,500	O	60	2,600	1,270	9,900	2.6	6.8
4,500	O	60	4,300	2,100	16,400	1.8	6.0
4,500	O	60	8,800	3,900	30,000	1.3	5.5
4,500	O	60	13,700	6,200	48,000	1.1	5.3
4,500	O	60	23,000	9,800	76,000	0.9	5.0
4,500	O	60	24,000	10,400	81,000	0.8	4.8
4,500	O	60	39,000	14,200	111,000	0.8	5.0
4,500	CO	60	1,150	510	4,000	3.5	7.3
4,500	CO	60	2,300	1,130	8,800	2.5	6.8
4,500	CO	60	72,00	3,300	26,000	1.5	5.8
4,500	CO	60	23,000	9,600	75,000	1.1	5.0
4,500	CO	60	32,000	12,200	95,000	1.1	5.0
4,500	CO**	60	30,000	11,600	90,000	0.9	5.0
4,500	CO**	60	31,000	12,900	100,000	1.0	5.0
4,500	CO**	60	41,000	15,000	117,000	0.8	4.8
4,500	CO**	60	43,000	16,000	125,000	0.6	4.5

* Times for last two phases to clear.

† O = opening, CO = closing opening.

** Duty cycle CO plus 15 seconds CO.

Interrupting Performance

Table I presents a group of consecutive interrupting tests made on one three-phase breaker, rated at 5,000 volts 100,000 kva. The table presents 4,500-volt and 2,300-volt tests, showing both opening and closing-opening performance on a three-phase circuit. At the end of this series of tests the breaker had made some 870 operations, of which over 600 were made on a power life test at 750 amperes, 65 interruptions were over 50,000 kva, 40 interruptions were over

75,000 kva, and 25 interruptions were over 100,000 kva.

The above tests were conducted on circuit connections whose recovery characteristics are described by curve *B* of figure 2. Throughout these tests frequent inspection revealed no need for mandatory maintenance. The breaker, during interruption, gave only a muffled report which was quite inoffensive. There was no visible disturbance or fire from the breaker throughout the limits of its interrupting rating. Following the above series the breaker withstood standard one-minute high-potential tests. An inspection of each chute following these tests revealed that interruption took place within the chute at a developed arc length considerably less than the longest available arc path. This knowledge was helpful in establishing a safe margin of performance to be discussed later.

A close analysis of the performance of the Magne-Blast breaker reveals a striking resemblance to the principles of interruption of a d-c circuit. That is, from the instant of contact parting the arc resistance increases. In both the a-c and d-c circuit this defines a reduction of circuit current. The a-c circuit, however, is blessed with current zeros which afford natural points of interruption. In contrast, the creation of an increasing arc resistance within an a-c air interrupting device accomplishes two major functions which co-operate to bring the current to an early interruption. These are: (1) rapid increase of energy absorption by the arc chute, interruption being forecast when the rate of absorbing the arc energy exceeds its rate of liberation, and (2) a change in the phase angle of the circuit from a zero power factor or phase angle of 90 degrees to a phase angle around 40 degrees to 50 degrees at interruption. With this changing phase angle the circuit is rapidly approaching a unity-power-factor condition where, in the limit, the current is in phase with the voltage and both approach zero together. It is common experience that the interruption of such a unity-power-factor circuit is quite easy because of the extremely low voltage following current-zero interruption. Conversely the arc of an oil breaker introduces little resistance with practically no improvement in phase angle. A breaker using oil as a dielectric withstands the full shock of the circuit recovery characteristic. Because of this fact, the true importance and significance of recovery characteristics were first revealed in connection with the oil device. This knowledge now goes forward to aid the air device. It follows, therefore, that with the decreasing phase angle and reducing arc current in the Magne-Blast breaker the recovery characteristics are improving with each successive current zero. It is of importance to note that the breaker clears when the phase angle is in the neighborhood of 40 degrees or less. The arc chute, to be described later, is uniquely designed to incorporate sufficient arc resistance to bring the circuit to within a few degrees of unity power factor had the current persisted beyond a phase angle of 40 degrees. The phase angle at interruption being approximately 40 degrees defines an ample margin in performance. These features are sketched in figure 3 showing the relationship between the recovery characteristics of a unity- and zero-power-factor interruption together with the Magne-Blast performance. The extremely high damping associated with what high-frequency transients remain in an interruption is brought about by the unique configuration which aids the gaseous products immediately following interruption to form a short-lived leakage path across the breaker. Some form of transitory leakage path has always been one of Mother Nature's methods of protecting

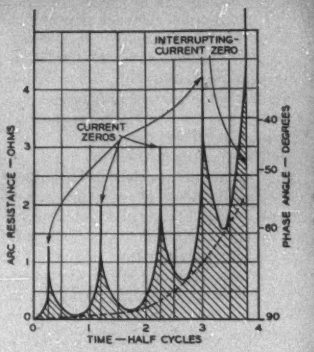

Figure 5. A curve of instantaneous arc resistance for time in half cycles

The increase of arc resistance to a circuit of constant reactance decreases the phase angle as shown. This curve is plotted from figure 3 and indicates the effect of an offset current wave

the air device. This phenomenon, working together with the large swing in phase angle exhibited by the breaker during interruption, accounts for the enormous reduction in recovery rate and peak recovery voltage immediately following interruption. This reduction in recovery rate is shown in figure 2 and forms an important link in the interruption sequence. Here, regardless of the station recovery characteristics (curves *A*, *B*, or *C*), the breaker responds with the recovery rate characteristic *D* shown at the bottom of the figure. This immunity to circuit characteristics has an important bearing on breaker application, as mentioned previously.

Figure 4 is a typical oscillogram showing a Magne-Blast breaker interruption of a single-phase fault of 1,150 amperes. The instantaneous arc resistance is defined as the ratio of the increasing arc voltage to the decreasing arc current. This instantaneous resistance is plotted in figure 5 for the test of figure 4. During any half cycle of current the minimum resistance occurs, as would be expected, near the current crest. However, this minimum resistance increases for each successive half cycle until resistance on the last half cycle of arc is such a value that the phase angle of the circuit is close to or less than 60 degrees. At the next current zero the current is invariably extinguished.

Figure 6 shows a master plot of the minimum resistance of the last half cycle of arc for the tests of table I. This characteristic is shown in both linear and

Figure 4. An oscillogram of a 3,600-volt 1,150-ampere single-phase interruption

A—Cathode - ray-oscillograph trip indication
B—Breaker trip-coil current
C—Breaker travel record
D—Arc voltage across breaker terminals
E—Current through breaker
F—Generator voltage

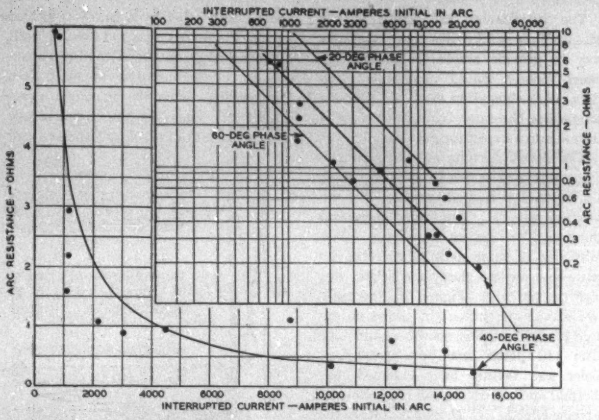
INTERRUPTED CURRENT—AMPERES INITIAL IN ARC
100 200 300 800 1000 2000 3000 6000 10,000 20,000 60,000
20-DEG PHASE ANGLE
60-DEG PHASE ANGLE
40-DEG PHASE ANGLE
ARC RESISTANCE—OHMS
ARC RESISTANCE—OHMS
0 2000 4000 6000 8000 10,000 12,000 14,000 16,000
INTERRUPTED CURRENT—AMPERES INITIAL IN ARC

Figure 6. Shows the interrupted current, initial amperes in arc plotted against the minimum resistance introduced in the last half cycle of current

The points are plotted on logarithmic and linear scales showing the curves of the resistances necessary to give a 40-degree phase angle on both scales and the 60-degree and 20-degree phase angles on the logarithmic scale. The tests plotted on this curve are all single phase

logarithmic form. The latter shows the remarkable fact of a straight line at −45 degrees slope which, in turn, defines a constant-power-factor characteristic. The phase angles of the lines shown are indicated on the curves.

The effect of arc resistance for the test of figure 4 is shown in quite different form in the static vector diagram of figure 7. Here the arc voltages for the four half cycles of the arc are shown by the horizontal vectors marked 1, 2, 3, and 4, respectively. Each half cycle of arc current is shown in instantaneous magnitude and phase-angle relationship to the circuit voltage. Figure 6 gives a graphical interpretation of the several simultaneous changes which are taking place within the circuit, namely, the current reduction, the increase in arc voltage, and the reduction of phase angle. It will be noted that the phase angle, as the current approaches its final zero, is somewhat closer to the voltage than indicated by the phase angle at the peak of the last current loop, the latter being shown in general form in figure 4. This characteristic is true of each of the current loops giving a sort of hysteresis effect. This phenomena shows that a very important cooling effect starts near the current peak continuing up to current zero. This rapid cooling as the current approaches zero plays a predominant part in determining the final clearing. It might be said that the interrupting process starts during the last quarter cycle of arc. These features will take added significance when the novel chute design, presented later, is studied from an electrical and thermal aspect.

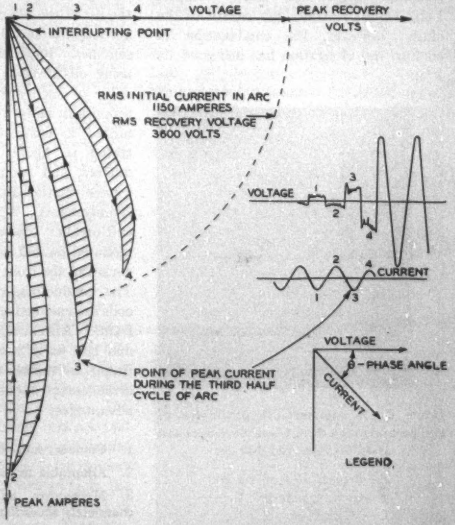

Figure 7. Polar diagram of a low-current interruption test

The schematic oscillogram (copies from figure 4) illustrates the current and voltage traces. The polar diagram illustrates the instantaneous values of current, voltage, and phase angle for each half cycle as arc resistance increases in value

Figure 8 presents the clearing of two poles of a three-phase ungrounded fault of 125,000 kva at 4,500 volts. The upper trace shows the first pole to clear, while the lower is typical of the last pole to clear. Following the first phase to clear, the remaining phases clear in series. Because of the compounding of the series arc resistances of the two remaining phases, together with the fact that they clear later, the final clearing usually takes place at an extremely low phase angle.

Before starting an extended series of interruption tests the breaker was tested to determine the effect of rapid duty. A normal operating load was established and interrupted once every 30 seconds until more than 600 operations were recorded. The breaker required no cooling as it continued its operations on this reactive circuit of 750 amperes at 4,500 volts. A series of 140 interruption tests were then completed. Of this number 65 interruptions exceeded 50,000 kva and 25 were of more than 100,000 kva. Standard one-minute high-potential tests showed no reduction in insulation values. After this complete series the breaker was disassembled and inspected. Of all details, the arcing tips alone required maintenance or replacement.

Description

The performance of the Magne-Blast air circuit breaker emphasizes the importance of a controlled increase in arc resistance. This resistance can be effec-

tively increased at a controlled rate by cooling and lengthening the arc stream during circuit interruption. The interleaving or serpentine arc chute as used on this breaker, figure 9, is a simple and reliable method for cooling and lengthening the arc in a manner consistent with circuit requirements.

Interrupter

As evidenced by its name, the interleaving chute is formed by long tapered fins alternating from either arc-chute wall, extending from the throat and arc runner to the mouth of the arc chute. Placed parallel to each other and spaced to leave room for the arc to fold in and out between opposite fins, their gradual taper away from the side walls permits the arc to form in a straight line without obstruction. As the arc stream is driven deeper into the chute, however, it is gradually forced to depart from its straight line as the fins cross deeper and deeper into the space between fins of the opposing side. The arc encounters an ever-increasing cooling effect as its path becomes longer and more tortuous. Long before reaching the mouth of the chute, however, the combination of cooling and elongation has increased its resistance to a critical value and the arc is extinguished. Though a sufficient untraveled path remains to provide a greater arc resistance and a further decrease in phase angle, tests show this is but a safety factor.

Figure 8. A representative oscillogram of two poles during a three-phase close-open test at 4,500 volts, 125,000 kva

A—Breaker-trip-coil current
B—Current, pole 2
C—Voltage, pole 2
D—Current, pole 3
E—Voltage, pole 3
F—Breaker travel

The interleaving arc chute of the Magne-Blast breaker has proved a simple way to provide ample arc cooling between closely spaced nonmetallic barriers. Arc elongation demands no compromise as the same barriers nicely fold the arc into a serpentine pattern.

The design permits moulding an arc-chute side and its fins in one piece using an especially treated arc-resistant insulation material. Continued operations show no ill effects on the chutes. Performance is unaffected, though the intense heat forms a glassy and pebbly surface on the fins. Figure 10 illustrates two sets of arc chutes. *A* shows an unused chute. At *B* is shown a chute side after 140 power tests to 130,000 kva. Color and texture have changed, but thermal and electrical properties show no adverse effects. *C*, *D*, and *E* picture the throat end, the side, and the mouth of completed arc chutes ready for mounting in a breaker.

Breaker Arrangement

Early agreement encouraged a geometric arrangement that would permit the use of the Magne-Blast air breaker in vertical-lift metal-clad switchgear assemblies. Experience with such gear using oil breakers has long proved the value of such arrangements. No compromise in performance or cost was permitted in completing the design illustrated in figure 11. Terminals, conductors, and operating structures show a close relationship to oil-circuit-breaker arrangements. A conventional oil-circuit-breaker operating mechanism is mounted on and isolated by a steel plate enclosing the front of the breaker frame. The conductors, contacts, and current coils are enclosed within the rigid breaker frame. Arc chutes, arc runners, mufflers, and box barriers extend back from the frame to define the boundaries. The arrangement is desirable from the listed advantages:

1. Compact and efficient in space.
2. Adaptable to vertical-lift metal-clad.
3. Mechanism and control accessories completely accessible.
4. Breaker completely isolated from mechanism and operating side.
5. All breaker parts are exposed by the ready removal of the insulated-box barrier.

Figure 11 illustrates the features of this arrangement in some detail. The complete interrupter and contact structure is mounted on and between the two insulated breaker bushings. These bushings are rigidly connected to the frame and to each other by a heavy insulated barrier *J*. Arc runners and blowout coils are mounted on and insulated from bushing *G*. A copper casting extending from this bushing carries the primary contact fingers *A*. These fingers complete the current circuit to the contact arm through solid-silver inlays. The inverted arrangement of these fingers provides an increase in contacting pressure from the magnetic forces at high currents. From the movable contact arm the current enters bushing *H* at the pivot. A connection between this bushing and the lower blowout coil of the arc chute carries current during interruption and provides an additional support for the arc chute and muffler. The arc-chute assembly can be easily removed to expose the complete assembly of contacts and arc runners.

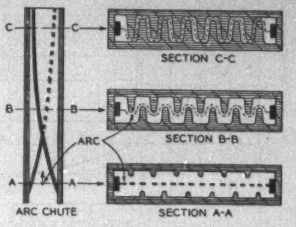

Figure 9. A schematic diagram showing the treatment of an arc in the Magne-Blast interrupter

At section *A-A* the arc is struck in a line between arc runners, as it is forced into the chute the fins constrict the arc and force it into a serpentine path *B-B*. Section *C-C* shows its final shape under extreme conditions

Current Transfer

To follow the treatment given the current during breaker opening, reference is made to figure 12. As the blade starts down, current is transferred from the primary contact *A* to the intermediate contacts *B*. Low-voltage arcing, as the blowout coil *E* is first shunted in, is taken on the parting of the intermediate contacts, to the benefit of the more sensitive primaries. As these intermediate contacts part, all current is shunted through the blowout coil and magnetic flux is created to force the arc on its way. Finally, the silver-tungsten arc contacts part *C*, the resultant arc is forcibly driven from the contacts adding additional blowout coils to the circuit as the arc travels along the runners *D*. For heavy currents this travel is so rapid that the arc is

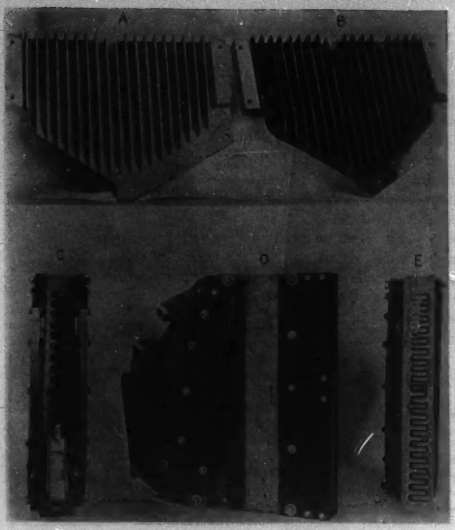

Figure 10. A finished arc chute for the Magne-Blast air circuit breaker

A—Shows one-half of an unused arc chute

B—Shows a similar half after 140 power interruptions to 130,000 kva. The discoloration of *B* indicates a surface change that has no effect on the thermal or electrical properties of the arc chute

C—Is taken from the throat or contact side of the arc chute

D—Shows the side of the arc chute

E—Illustrates the serpentine pattern at the mouth of the arc chute with muffler removed

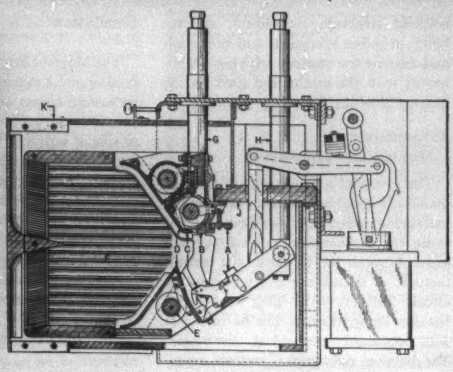

Figure 11. A sectional drawing of the 5,000-volt Magne-Blast air circuit breaker for 100,000-kva interrupting capacity

A—Primary contact fingers and movable contacts
B—Intermediate contacts
C—Arcing contacts and lower arc runner tip
D—Arc runners
E—Blowout core and coils
F—Inside of arc chute
G—Rear insulated bushing
H—Front insulated bushing
J—Horizontal tie barrier of insulation
K—Removable box barrier and vents

extinguished at a minimum break distance of one inch. As the arc terminus travels up along the upper arc runner it jumps an insulated gap and injects a second multiturn coil to maintain high flux densities in spite of current reduction. At the same time, the arc terminus has shifted to the lower runner *D* and has shunted in a third multiturn coil *E* that assists in arc travel in the lower portion of the chute. The travel of arc roots in divergent directions lengthens the arc, and, assisted by the driving force of the flux, forces it into the serpentine passage *F* on its way to extinction.

Heavy-current interruptions require throttling for the powerful magnetic blowouts at such currents may drive the arc through the chute before resistance and cooling are permitted to complete their functions. A muffler mounted on the end of the chute, pockets and retards air flow and directs all arc products into the streamlined deflectors forming the end of the box barrier. Before the gases reach this area all arc, arc flame, and gas has been cooled to a harmless value and final gases flow from the grilled openings at the top and bottom of the box barrier *K*, negligible in temperature, velocity, and potential. Maximum power interruptions are evidenced only by the small trickle of smoke from these openings and the dull thud that accompanies the formation of the initial arc.

Insulation

Bushings are designed and manufactured in accordance with oil-circuit-breaker standards. Because each pole is mounted on these bushings, the breaker is easily isolated into three phases. The extended barriers between phases and from phase to ground offer ample insulation and are flame resistant. Arc runners and blowout coils are separated from the side walls of the arc chute by sheets of inorganically bonded mica. This material, high in dielectric and mechanical strength, suffers no damage when exposed to power arcs. Operating rods of insulation are a strong link between the mechanism and the contact arms.

Operating Mechanism

Oil-circuit-breaker practices provide a valuable background when considering the requirements of an operating mechanism. Step-by-step evolution has brought the present-day solenoid mechanism to a high degree of perfection. Because this breaker so closely parallels modern oil circuit breakers in mechanical operation, it has been quite practical to use a standard operating mechanism. A modern oil-breaker solenoid mechanism contributes to performance when applied to this air circuit breaker. The mechanism requires but minor modifications when used as described. The features of an efficient

Figure 12. Contact structure and blowout coils. Half of arc chute assembly is removed

A—Primary contacts
B—Intermediate contacts
C—Arcing contacts
D—Arc runners
E—Blowout coils
F—Arc chute

solenoid structure; sturdiness, adaptability, trip-free operation, and potential- and current-transformer tripping are inherent with the mechanism used on the Magne-Blast circuit breaker (figure 1).

Arrangement in Metal-Clad Equipments

The compact arrangement of this air breaker loses no advantage when used in metal-clad switchgear equipments. Because the breaker does not exhaust hot gases beyond its barriers, the manufacturer of switchgear can use it as oil circuit breakers have long been used. Breaker compartments can be of metal with standard mechanical clearances. The breaker mechanism, control accessories, and secondary couplings are conveniently accessible from the front of the metal-clad equipment. Inspection and adjustment of these accessories can be completed without removing the breaker from its operating compartment.

Figure 13 illustrates the close relationship between such metal-clad equipments. *A* shows a metal clad using a 100,000-kva oil circuit breaker insulated for 7.5 kv. *B* shows, to a similar scale, a metal-clad equipment with a 100,000-kva "Magne-Blast" air breaker insulated for 7.5 kv.

Conclusion

The Magne-Blast air circuit breaker, by cooling and lengthening the arc in an interleaving chute, adds resistance to the circuit as the arc is extinguished. Rates of rise of recovery voltage are held to a harmless value. The breaker has demonstrated the characteristics of long and economical life, reliable circuit control, and a reduction of hot gases and disturbances when interrupting high currents. The physical arrangement permits its use in vertical-lift metal-clad gear where a compact arrangement is possible without infringing on the accessibility of the mechanism or control accessories.

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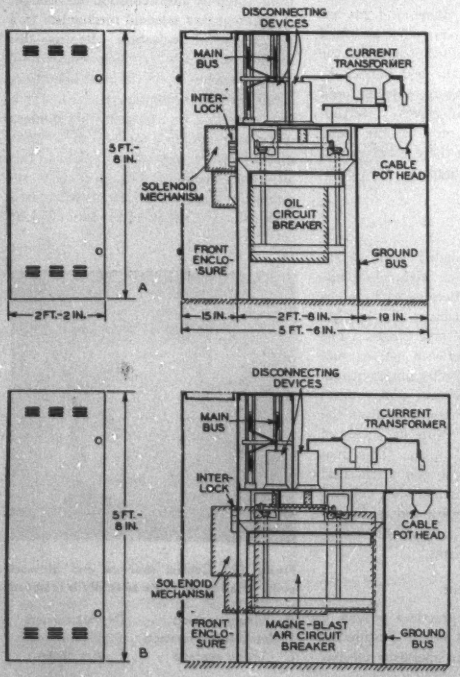

Figure 13. Breaker arrangement in a metal-clad equipment

A—An oil circuit breaker rated at 100,000 kva insulated for 7.5 kv in typical vertical-lift metal-clad equipment

B—A Magne-Blast air circuit breaker rated at 100,000 kva with 7.5 kv insulation used in a comparable metal-clad equipment

Discussion

Elias S. Cornell (Delta-Star Electric Company, Chicago, Ill.): This paper discloses an interesting development in oilless-circuit-breaker design. The mechanical and electrical complexities which seem to characterize this entire class of circuit interrupters, do not however appear to be materially reduced.

Elimination of oil or other liquids will be favorably regarded from the standpoint of maintenance. However, there appears to be a greater number of active parts such as increased number of arcing contacts, the addition of large arcing chutes, and blowout coils. Whether or not the net result will be an improved maintenance condition, only operators can tell—and time for experience should be allowed before definite conclusions can be drawn.

It is particularly interesting that this paper introduces the first oilless circuit breakers adaptable for vertical-lift type of metal-clad switchgear. Designers and operators have recognized that the vertical-lift construction possesses many electrical, mechanical, and space preserving advantages over the draw-out or truck type design.

On the other hand, modern oil circuit breakers are of clean-cut design with few working parts. Experience with this type has been so generally good that before the oilless can supplant present modern oil circuit breakers, a unit more simple mechanically and electrically must emerge from the various designs now suggested.

I shall look forward to further developments of the oilless circuit breaker of which this paper is the latest contribution.

C. G. Suits (nonmember; General Electric Company, Schenectady, N. Y.): Messrs. Boehne and Linde are to be congratulated for the excellent application which they have made of thermal principles of arc interruption. Although these principles are not entirely novel, they have been carried in the present instance to new limits which bespeak the authors' fine appreciation of the underlying arc phenomena.

The means of interrupting an arc by cooling has been employed to an accidental extent in many circuit-breaking devices in the past, but it has only been with recent advances in our knowledge of the fundamentals of this process that engineers have employed it as a design principle.

It may be of interest to review some of the fundamentals involved in the interruption principle of this circuit breaker as illustrative of the influence of thermal factors on the electrical properties of arcs.

The most important underlying fact is this: In a high-pressure discharge electrons

are in thermal equilibrium with the neutral gas, a concept first proposed by K. T. Compton.[1] The electrons acquire kinetic energy by virtue of their acceleration in the field between the electrodes, and lose a small fraction of this energy (determined by the ratio of masses) to the gas molecules in each collision. At some high gas pressure and correspondingly high collision frequency it will be impossible for the electron energies to exceed the gas energies. This implied condition for thermal equilibrium can be defined more rigorously by stating that the energy gained from the field by the electron per mean free path must be small compared to the thermal energy; thus

$$\Delta Ve << \frac{3}{2}kT$$

where ΔV is the average potential difference through which the electron of charge e falls per collision. Here k is the Boltzmann constant and T the mean gas temperature. It is clear that this relationship is best satisfied at high pressure, and since the electric field in the arc column decreases with increasing current, at high current. The results of numerous investigations[2] show that even in low-current arcs at atmospheric pressure in air the equilibrium between electrons and gas is established.

This fact has important consequences in circuit interruption, the first of which is: the *ionization density* is fixed by the *gas temperature* (identical with the electron temperature), and neither of these two quantities can be changed without altering the other. When a volume of arc gas is cooled, its ionization density is reduced thereby. Moreover, the relation between ionization density n and temperature T is a quantitative one,[3] being given by the equation

$$\log_{10}\left(\frac{n^2}{N}\right) = -\frac{5{,}040V}{T} + \frac{3}{2}\log_{10} T + 15.38$$

where V is the ionization potential of the neutral gas of molecular density N. It is interesting to note the sensitivity of ionization density to temperature, particularly at the temperatures around 2,000–3,000 degrees Kelvin which have been observed around the current zeros of some a-c arcs.[4] This is shown by table I of this discussion, where ΔT is the temperature difference required to double the ionization density at the mean gas temperature T. Thus a change of only 30 degrees will double the ionization density at 2,000 degrees Kelvin. It is not difficult to understand, therefore, how removal of heat by the circuit-breaker chute structure is effective in reducing the conductivity of the arc gas at the current zero.

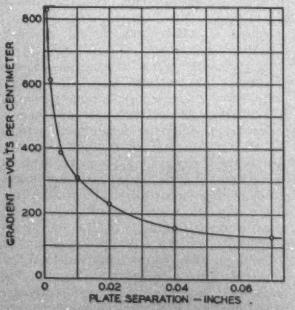

Figure 1. Electric gradient for an arc between flat insulating plates at different separations

A second consequence of the thermal equilibrium in the high-pressure arc is this: It is impossible to change the direction of momentum of the conducting electrons, as, for example, by a magnetic field, without also acting upon the neutral gas. This is a consequence of the high rate of energy transfer at high pressure. Thus we do not sweep out the electron cloud as a separable quantity with the magnetic field. We move the electrons and the gas; in short, the arc column. For that reason we find that when a d-c arc is wiggled by an a-c field perpendicular to its axis, its maximum translational velocity is a very small fraction of the velocity which it reaches in a d-c field of the same magnitude. In some unpublished calculations, Doctor H. Poritsky found that to account satisfactorily for the velocity of the arc moved by a d-c magnetic field he had to use a value of mobility corresponding not to that of the electrons, but to that of a relatively immobile body, such as a positive ion. This is further evidence that the electron gas cannot move without dragging with it the neutral gas. It has, of course, long been known that because of the space charge it is impossible to separate the electrons from the positive ions in a plasma.

Considerations such as the above lead us to the application of heat transfer data to the arc column.[5] We can move an arc magnetically past an insulating plate and in cooling it thereby reduce its ionization density. This rather striking effect can be illustrated by a simple experiment in which the electric gradient in the arc column is measured for an arc between insulating plates with various spacings, as shown by the curve of figure 1 of this discussion. These measurements were taken for a steady-state d-c arc of 15 amperes, but they are believed to be illustrative of a general property of the high-pressure arc, whether it be d-c or a-c, high or low current. Similarly, we can investigate the effect of cooling on the current zero in a transient arc. This is illustrated by figure 2, where the cooling or "deionization" time τ is plotted as a function of plate separation for an arc burned between parallel insulating plates. In this experiment the d-c arc current of 15 amperes is suddenly reduced to zero for an adjustable interval and then voltage is suddenly reapplied. The time τ is the minimum interval which will prevent re-establishment of current. It decreases with smaller plate spacing as a result of the more effective cooling.

Table I. Temperature Difference ΔT to Double Ionization Density at Mean Temperature T

T (Deg K)	ΔT
7,000	400
6,000	300
5,000	210
4,000	130
3,000	78
2,000	30

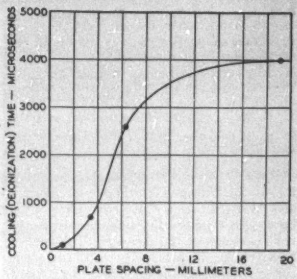

Figure 2. Cooling time of arcs between insulating plates, for different spacings

In applying heat-transfer principles to their circuit breaker, the authors have arrived at a form of cooling structure which in a unique way satisfies many diverse practical requirements in addition to the prime function of extracting heat. Thus the desirable lengthening of the arc column brings with it the advantage of a longer parallel insulation path at the time of the current zero. This particular insulation path, because of its higher temperature, is most vulnerable to surface flashover. The folding of the arc column is accomplished in the plane perpendicular to the plane of the arc motion. This is important because folding in any other plane will bring with it some components of magnetic field (due to the current upon itself) which oppose the blowout field.

It is interesting to point out that in this breaker we observe a real current-limiting action, analogous in many ways to the phenomena of the current-limiting fuse.[6] As a result of recent work we now know beyond question that this fuse is a real arc interrupting device wherein a high gradient is developed in an arc in a tube of fused quartz. This fact apparently escaped the original investigators.[7,8] These data will be reported more completely elsewhere.

That the principle of arc interruption by cooling will have wider development and that heat transfer engineering will be further applied to circuit breaker design seem certain by the remarkable performance of the authors' Magne-Blast breaker.

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R. C. Dickinson (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Since the announcement over ten years ago of the pioneer in the field of high-voltage high-capacity modern oilless circuit breakers, the "De-ion" air circuit breaker, several types of oilless circuit breakers have made their appearance. This latest device, presented by Messrs. Boehne and Linde, draws an arc and increases its voltage to such an extent that the circuit potential cannot maintain it. Thus, principles heretofore applied only to low-voltage interrupting devices, have been extended to a higher-voltage class. This is accomplished in approximately the space of competitive breakers by refinement in the design in the interrupting element.

It is now recognized that a good principal of circuit breaker design is to keep the arc energy of the interrupting element as low as possible, thereby minimizing distress on the breaker in general. The arc energy is a function of the integrated arc voltage with respect to time and, therefore, it has always appeared good practice either to keep the arc voltage low except near the current zero, or to keep the interrupting time very short. In view of this it comes somewhat of a surprise to hear high arc voltage in a circuit interrupting device proclaimed as an advantage.

Fundamentally, the device described seems to operate on the long established principal of stretching the arc out to great length, thereby developing sufficiently high arc voltage to prevent the circuit voltage from maintaining it. The resulting arc voltage is sufficient to cause a shifting of the point of interrupting from the crest of the a-c wave (for a zero-power-factor circuit) toward the zero point, which thereby reduces the magnitude of the resulting transient in proportion to the system-frequency phase shift. Any other reduction in the transient peak must evidently be caused by leakage. The author states that such leakage does occur in this device and that this leakage is through a path formed by gaseous products. We would expect this leakage effect to vary considerably over the interrupted current range. That is, it would be more pronounced at high current values. This would make the breaker largely dependent purely upon the development of arc voltage at the low current values. We would also expect the development of arc voltage to be decreased at low current values due to the weaker blowout effect and to the decreasing effect of the restriction of the arc path formed by the narrow serpentine slot. Therefore, we would be interested to know how this breaker performs on low current values such as magnetizing currents.

In discussing the authors' explanation of the operation of this breaker, we call attention to a statement by D. C. Prince in his discussion of "Arc Extinction Phenomena in High-Voltage Circuit Breakers Studied With the Cathode-Ray Oscillograph" by Messrs. Van Sickle and Berkey:[1] "The modification produced in the circuit recovery rate by these (oil) breakers is due to their attempting to clear the circuit at times other than normal current zero or to conduction of small currents without a complete breakdown of the dielectric. These characteristics tend to produce distress in the circuit breaker, as it is required to absorb energy normally stored in the electric circuit." We would thus conclude that this is a high-energy device and is, therefore, subject to considerable stress in interrupting short-circuit current. Thus, it is primarily dependent upon a characteristic making it necessary for it to absorb relatively high energy in order to interrupt the circuit.

In the De-ion air circuit breaker, we have a shifting of the point of interruption on the 60-cycle voltage wave which is most pronounced at high current value. As shown by the oscillogram of figure 10*A*, in the paper on De-ion air breakers for 2,500 and 5,000 volts, in AIEE TRANSACTIONS for November 1938, this phase shift is of about the same order as shown by Messrs. Boehne and Linde. However, the interrupting principles of the De-ion air circuit breaker include a very definite voltage interrupting characteristic produced by the rapid growth of dielectric in a multiplicity of cathode layers.[2] Its interrupting characteristic is therefore independent of line current and, for all practical purposes is independent of the circuit recovery characteristics. The reduction in transient peak caused by the phase shift at high current in the De-ion air breaker is not relied upon for circuit interruption and is merely incidental in its performance. Also, in the De-ion air breaker, no critical damping of the recovery transient due to gaseous leakage paths has been observed.

REFERENCES

1. AIEE TRANSACTIONS, September 1933.

2. THEORY OF THE "DE-ION" AIR CIRCUIT BREAKER, J. Slepian. AIEE TRANSACTIONS, April 1929.

V. L. Cox (General Electric Company, Philadelphia, Pa.): This new design of oilless circuit interrupter will find many fields of application especially where frequent operations are necessary for motor starting, jogging, reversing, furnace control, and reclosing feeder service.

In designing this breaker, the design engineers kept in close touch with the engineers responsible for switchgear assemblies, and the result is a breaker that can be fitted into present oil-circuit-breaker equipment designs with practically no change in arrangement of apparatus and over-all dimensions. It was early recognized that the contour of the air breaker should conform as closely as possible to that of the oil breaker in order to conserve space in the usual switching structure. It has long been recognized that the most economical arrangement, for the combination of busses, breaker, current transformers, potential transformers, and the take away of primary cables (up or down) can be accomplished only with this particular contour.

The ideal structure for mounting the new breaker is metal-clad switchgear. It has been possible to retain the vertical lift, easily removable circuit-breaker feature which has been found so useful in oil-circuit-breaker metal-clad switchgear. The advantage is the continuance of a design which has proved its utility in the field; no new station designs are necessary nor need any conceptions of this type of equipment be changed.

The use of an oilless circuit interrupter in metal-clad switchgear puts the metal-clad type of switching structure even higher up the pinnacle of design attainment for factory-built shipped-assembled units. The safety to personnel, protection to circuits, co-ordinated design, ease of installation and maintenance, high level of insulation, and unit construction employed in metal-clad switchgear make this type of switching structure the best. This holds true for the oil or oilless breakers, but due to the absence of inflammable liquid, the installation of the new breakers can be made in locations not best for oil circuit breakers.

Tracing the history of metal-clad switchgear back to its inception, both in Europe and in this country, we find that there has been a definite trend from the compound and oil-filled structure insulating medium toward the air-filled type. The high-voltage air-breaker development is another step in this direction in its now complete elimination of this liquid.

D. C. Prince (General Electric Company, Philadelphia, Pa.): In domestic refrigerators we have gone through the stage of units separate, units above, and units below the box. By trying all combinations the most generally satisfactory has emerged. Likewise in the automobile, we have tried engines beneath the seats, engines in front, and engines in the rear. Each arrangement has its advantages, but, in general, the logic of the situation has begun to clarify itself.

Until recently circuit breakers were more or less alike. Then a perfect rash of variations broke out in Europe. A person fully familiar with our standard tank-type of circuit breakers might not even recognize one of the current European productions for what it is.

The use of oil in a tank determines to a certain extent the configuration of the parts of a circuit breaker. In a circuit breaker such as the Magne-Blast, this criterion is absent and in its absence the situation regarding the whole arrangement problem should be reconsidered.

In Europe the threat of war and scarcity of various raw materials may effect evolution; also, different maintenance practices and different service standards may put a premium on different elements of design. We must, therefore, go through our own evolutionary process, as we have done in connection with the refrigerators and automobiles, to see what physical arrangement, in the absence of the limitations of an oil vessel, lends itself best to the industry's needs.

This question cannot be satisfactorily answered in the laboratory. The next few years will, therefore, see many excursions away from past conventional circuit-breaker practices. In the end the most suitable designs will evolve. For the sake of the

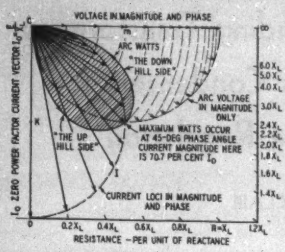
VOLTAGE IN MAGNITUDE AND PHASE
ARC WATTS
"THE DOWN HILL SIDE"
ARC VOLTAGE IN MAGNITUDE ONLY
"THE UP HILL SIDE"
MAXIMUM WATTS OCCUR AT 45-DEG PHASE ANGLE CURRENT MAGNITUDE HERE IS 70.7 PER CENT I_0
CURRENT LOCI IN MAGNITUDE AND PHASE
I_0 ZERO POWER FACTOR CURRENT VECTOR
RESISTANCE — PER UNIT OF REACTANCE

Figure 3. Polar diagram showing the inseparable relations between phase shifting, current reduction, and watts as resistance is inserted into an inductive circuit

Note: Maximum watts occur at 45-degree phase angle when the current is only 70.7 per cent of its zero-power-factor value

industry, let us hope that such evolution can be brought about with a minimum of false starts and costs for all concerned. However, nature is a severe taskmaster. We must evolve to meet changing conditions or join the dinosaur.

E. W. Boehne and L. J. Linde: The development of the Magne-Blast breaker is the natural growth of the General Electric Company's oilless devices of high interrupting capacity pioneered by our company's transportation department and presented in excellent papers in 1922 ["Air-Break Magnetic Blowouts (For Contactors and Circuit Breakers Both A-C and D-C)," J. F. Tritle, AIEE TRANSACTIONS, 1922, page 262]. The interleaving chute has enabled appropriate rating to be literally folded into sizes and arrangements suitable for standard vertical-lift metal-clad gear. The development embodies the contributions of the past, the contributions of a fuller knowledge of recovery rates as offered by the oil device; the contributions of our research studies of arcs in various environments, together with novel arrangements in mechanical design.

Figure 4. Single-phase interruption of 22,000 amperes at 2,600 volts by a Magne-Blast breaker

Note current reduction to 46 per cent of previous loop and low phase angle at interruption

A—Trip-coil current
B—Bus voltage
C—Short-circuit current
D—Arc voltage
E—Cathode-ray trip

The authors are greatly indebted to Doctor Suits for his discussion of the problems of circuit interruption in air. His investigations of arc phenomena have considerably reduced the mysteries of such arcs and have shown us the importance of the thermal as well as the electrical factors of this general problem. The interleaving arc chute meets all thermal demands as well as the electrical requirements of an interrupting device.

Mr. Cornell points to the clean-cut design and few working parts of modern oil circuit breakers as contrasted to the apparent complexity of any oilless circuit breaker design. Blowout coils, arc chutes, and insulations do add to the complex appearance of an oilless breaker. Apparent complexity, however, can only be evaluated as it influences performance and maintenance expense. We are fortunate in having a complete historical background covering the performance and life expenses of magnetic-blowout-type air-circuit-breaker constructions. During many years the type *JR* high-voltage air circuit breaker has maintained an excellent reputation for performance and life in the industrial and transportation fields. The Magne-Blast breaker incorporates a similar blowout-coil construction.

As a contribution to easy inspection and maintenance, the enclosing box barrier may be readily removed to expose the arc chutes and contact structure. Arc chutes themselves are then easily removed when a more detailed inspection is being made, for then all arc runners, contacts, and blowout coils are accessible.

Figure 5. Oscillogram showing two phases of a three-phase CO interruption of 14,000 amperes at 4,500 volts by a Magne-Blast air circuit breaker

Note the low arc drop at current crest and the high arc drop at interruption

A—Trip-coil current
B—Phase *A* current
C—Voltage across phase *A*
D—Phase *B* current
E—Voltage across phase *B*
F—Travel record

We are in agreement with Mr. Cornell and Mr. Cox in their discussion of vertical-lift arrangements. This particular breaker arrangement is a direct result of the operators' and designers' recognition of the many advantages of the vertical-lift design over draw-out or truck designs for metal-clad switchgear.

To carry through with the points raised in Mr. Dickinson's discussion requires a clarification of the principle of arc interruption as demonstrated by the Magne-Blast breaker. The basic consideration is one of resistance. When resistance is uniformly inserted into an otherwise zero-power-factor circuit, the current is reduced, the power factor swings toward unity, and energy is dissipated in the resistance. These three changes are inseparable as clearly shown in the circle diagram of figure 3 of this discussion. Energy dissipation becomes maximum when the resistance in ohms equals the reactance in ohms and occurs, as shown in figure 3, at a phase angle of 45 degrees, simultaneous with a current reduction of only 30 per cent. The Magne-Blast breaker magnetically blasts the power arc into an efficient arc trap where the resistance characteristics are uniformly developed in the arc itself, and so effectively that energy dissipation is thrown over the hump of maximum energy dissipation and, as the decaying arc proceeds in the chute, it is literally on the "downhill side" toward interruption. See figure 3.

With the above fundamental relations in mind, it is a little difficult to unravel the apparent contradictions in Mr. Dickinson's discussion to the effect that the De-ion breaker exhibits comparable phase-angle

changes, marked arc-current reduction, while paragraph 2 of his discussion teaches the merits of keeping the arc energy of the interrupting element as low as possible.

Arc energy has been no problem in the Magne-Blast breaker, chiefly due to the controlled absence of all metal vapor from the main arc stream together with the exposure of the rapidly moving arc to increasing amounts of cool insulating surfaces. In the Magne-Blast breaker the arc duration of higher currents seldom exceeds one-half cycle. In this short interval the heat penetration into the surface walls of the interleaving chute is less than eight mils. That component of heat which is retained is partly absorbed into the fins of the chute, the larger share being carried off by convection currents immediately following interruption. These conclusions are necessary to account for the fact that following an exhaustive series of tests the breaker will be found as "cool as the proverbial cucumber."

This brings us to Mr. Dickinson's recommendation of high arc voltage near current zero. We heartily agree and refer to the two oscillograms in our paper as well as the two shown in this discussion, the latter of which bears considerable study. Note the low arc voltage at peak current in relation to the high arc voltage at interruption. This is the first time that this desirable characteristic has been observed in air breakers of this type. It is the characteristic result of a pure expanding arc, confined and cooled in the absence of metal vapor.

Recovery rate control by the Magne-Blast breaker is a natural refinement of one of the inherent properties of air interrupters employing magnetic-blowout action. It has only been through the evolution of oil breakers that the importance of recovery rates has been recognized. Low-gradient leakage paths available during the first 100 microseconds following interruption afford an excellent way to absorb the high-frequency components of recovery characteristics. This leakage path is through the gas confined to the chute during a brief recovery period following interruption and has only been detected by the absence of the high-frequency component of the recovery characteristic. The extreme length of this path deep within the chute together with its freedom from metal vapor accounts for this desirable shock-absorbing feature. The major factor in recovery-rate control, as previously demonstrated, is the large phase shift up to the point of interruption.

Low-current performance of the Magne-Blast breaker follows the same characteristics as the higher-current performance, namely, a continually increasing arc voltage, phase shifting, current reduction, followed by a positive interruption. These processes are naturally slower because of the slower movement of the arc along the runners.

The Magne-Blast breaker has been tested throughout the complete current range, that is, from 0.2 amperes upward, zero-power-magnetizing currents as well as similar currents on a leading-power-factor basis. These tests have been entirely satisfactory and are strengthened by the fact that, with this publication, breakers have been in service over a year performing satisfactorily where interruptions of regulator magnetizing currents are required daily.

The Use of Multiwinding Transformers With Synchronous Condensers for System Voltage Regulation

H. P. ST. CLAIR
MEMBER AIEE

THREE-WINDING transformer banks offer a convenient and economical means, and are frequently used, for operating synchronous condensers at step-down substations, particularly where the secondary voltage is too high for direct operation of the condenser. The usual function of the condenser in such cases is to regulate the secondary voltage, and the condenser regulator is controlled from that voltage rather than from the tertiary winding, or condenser terminal voltage. Furthermore, in many three-winding transformer designs the effect is nearly the same as though the condenser were actually operating on the secondary winding.

There are, however, many applications in which it is desirable to vary the transformer design and with it the condenser performance in order to accomplish a particular regulating and power factor correcting job which cannot be done with the usual three-winding design. A number of such applications, involving not only three-winding transformers but in some cases four-winding transformers as well, have been worked out and placed in operation with excellent results on the system of the American Gas and Electric Company.

While descriptions and analyses of the conventional three-winding transformer design have been presented and discussed in the technical literature (see bibliography), there is believed to have been little, if any, discussion of the possibilities of manipulating the equivalent reactance network of three-winding as well as four-winding transformers in order to co-ordinate or combine the main regulating function of the condenser with other more-or-less secondary regulating effects which may be desired. It is the purpose of this paper, therefore, to describe and classify the several types of transformer designs and regulating combinations that can be used in applying synchronous condensers with multiwinding transformers and to illustrate each type with examples of actual installations.

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Theory and Application of Three-Winding Transformers

It is recognized, as mentioned above, that the equivalent reactance network of three-winding transformers derived by means of the three-point formula has been amply published before, but for convenient reference in this paper it will be repeated here. The reactance network as shown in figure 1 takes the form of a star in which the legs A, B, and C are found by solving the three equations:

$$A+B=X_{pz}$$

$$A+C=X_{pt}$$

$$B+C=X_{zt}$$

The terms X_{pz}, X_{pt}, and X_{zt} are the reactances from primary to secondary, primary to tertiary, and secondary to tertiary, respectively, expressed in per

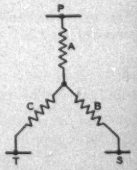

Figure 1. Equivalent-reactance network of three-winding transformer

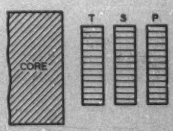

Figure 2. Probable arrangement of windings for type I transformers

cent or per unit values and of course all referred to the same kilovolt-ampere base. The solution of the above equations gives the following expressions for the three legs of the star:

$$\text{Leg } A = {}^1/_2(X_{ps} + X_{pt} - X_{st})$$

$$\text{Leg } B = {}^1/_2(X_{ps} + X_{st} - X_{pt})$$

$$\text{Leg } C = {}^1/_2(X_{pt} + X_{st} - X_{ps})$$

In transformers having the three windings placed successively on the core without interleaving, as shown in figure 2, one of the three legs of the star will have a relatively small value for the reason that the reactance between the two windings farthest apart will be roughly equal to the sum of the reactances between adjacent windings. For example, if in figure 2, $X_{pt} = X_{ps} + X_{st}$, then leg B in figure 1 will be zero. With interleaved windings, however, whether on the shell-type or core-type design, the straight-line reactance circuit no longer holds true and it is generally possible to obtain nearly any desired relationship between the values of A, B, and C in figure 1.

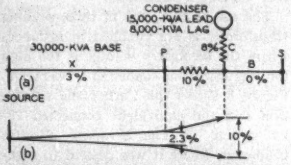

Figure 3. Typical application of type I three-winding transformer and condenser for ten-per cent no-load voltage range

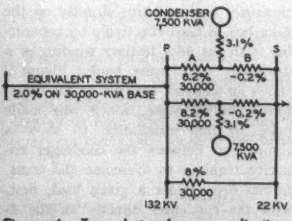

Figure 4. Type I transformer application, equivalent setup for Sunnyside substation, Canton, Ohio

When a synchronous condenser is connected to leg C of figure 1, obviously the relative values of A and B will directly affect the regulating performance and the range of voltage control obtainable with a given size of machine. The particular problem which will be dealt with in the discussion of the various types of installations presented in this paper will be the selection of these relative values, A and B, in the equivalent reactance network. The value of C affects the range of terminal voltage over which the condenser is required to operate, but for this discussion it will be assumed, as is generally true, that it offers no serious problem except the necessity of selecting the proper voltage ratings for condenser and transformer.

For convenience, the three-winding transformer designs discussed in this paper will be classified in three types according to the relative location of the synchronous condenser in the equivalent reactance network, that is, according to relative values of A and B in figure 1. The reason for this classification will appear in the following descriptions.

Type I—Conventional Three-Winding Designs With Condenser Regulating Secondary Voltage

In this type the equivalent reactance network of the transformer places the condenser electrically on or close to the secondary bus. A typical elementary layout for such a transformer and condenser combination is shown in figure 3*a* where the equivalent circuit legs A, B, and C correspond to the equivalent circuit shown in figure 1 and the transformer design would probably correspond to figure 2. To illustrate the actual performance of such a setup, typical values have been assigned as follows:

Transformer bank = 30,000 kva

Condenser rating = { 15,000 kva lead / 8,000 kva lag }

Equivalent reactance network of transformers:

A = 10 per cent
B = 0 per cent
C = 8 per cent

Equivalent system reactance to high side of transformer = 3 per cent on 30,000 kva

The proper system reactance to use in this elementary diagram is not the total reactance back to the source, including generator reactances, etc., but only that part of the system reactance between the point of installation being considered and the nearest point or combination of points at which system voltage is normally maintained at a constant level. This value of reactance will usually be much smaller than the total system reactance ordinarily used to determine short-circuit current at the particular location. This reduced value of reactance is used in all the elementary diagrams covering the actual installations described below.

Fig. 3*b* shows graphically the voltage range over which the condenser by itself with no load on the system would be able to swing the secondary voltage,

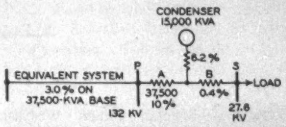

Figure 5. Type I transformer application, equivalent setup for Riverside substation, Benton Harbor, Mich.

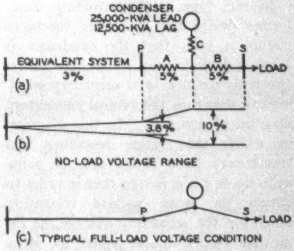

Figure 6. Typical application of type II three-winding transformer and condenser for ten-per cent no-load voltage range

in this case a total of ten per cent. This means, in other words, that the condenser would be capable of maintaining flat regulation on the secondary bus if the natural regulation due to load variation amounted to ten per cent without correction.

Typical three-winding transformer installations of the type I design on the American Gas and Electric Company system are in service at Sunnyside substation, Canton, Ohio, and Riverside substation, Benton Harbor, Mich. Equivalent reactance diagrams for each of these installations are shown in figures 4 and 5, respectively. In these installations as in a number of others of the same type, the condenser or condensers are arranged to regulate the secondary bus voltage and, as far as electrical performance is concerned, the condensers might just as well have been connected directly to the secondary bus. The only purpose of the three-winding transformer is to avoid the necessity of a second transformer bank and associated switching equipment which would otherwise be required to operate the synchronous condensers.

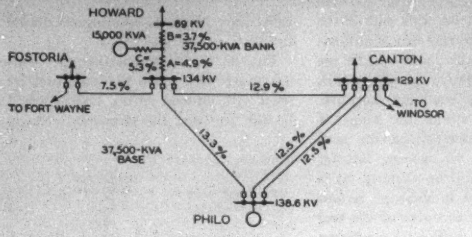

Figure 7. Type II transformer application, equivalent setup for Howard substation, near Shelby, Ohio

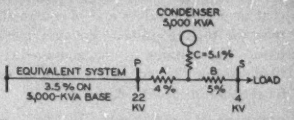

Figure 8. Type II transformer application, equivalent setup for Carbondale substation, Carbondale, Pa.

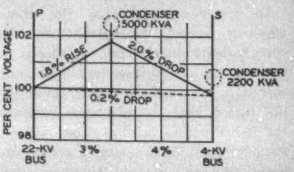

Figure 9. Comparison of condenser capacity required with three-winding and two-winding transformers, for Carbondale substation, Carbondale, Pa.

Type II—Special Three-Winding Transformer Designs With Condenser Regulating Secondary Voltage But With Increased Effect on Primary Voltage

In this type of three-winding transformer design the equivalent reactance circuit is such that the condenser is connected electrically somewhere in between the primary and secondary windings as shown in the typical elementary diagram of figure 6*a*. In this diagram, in which the system reactance and transformer bank rating are the same as in figure 3*a*, it is seen that in order to obtain the same no-load regulating range for the secondary voltage, as indicated graphically in figure 6*b*, it is necessary to use a synchronous condenser of nearly double the size. Figure 6*c* shows graphically a typical full-load condition for this setup, in which it will be observed that the condenser must be larger, not only because the total reactance *A* plus the system reactance, on which the condenser operates is smaller than in figure 3*a*, but also because of the necessity of overcoming the uncorrected voltage drop in leg *B* produced by the secondary load.

The purpose of such a transformer design is to provide regulation, primarily for the secondary bus voltage, but at the same time to utilize *more* synchronous condenser capacity than would be required with the type I transformer design, thereby giving greater correction to the high-voltage system. If the daily load curve for the local load supplied from the secondary bus is somewhat similar to the high-voltage-system load curve, then t is possible with this scheme to obtain fairly flat regulation on the high-voltage bus at the same time that the secondary bus is being held constant. To approach this result it is a fairly simple matter to determine the relative values for *A* and *B* and the condenser capacity required, taking into account of course the system load and impedance characteristics and the local secondary load.

Obviously, the larger leg *B* (figure 6*a*) is made with respect to *A*, the greater the condenser capacity required to hold the secondary voltage constant. Often the condenser size is limited by the size of the transformer bank, which in turn is fixed by the amount of secondary load to be handled. In such cases the problem becomes one of selecting relative values for legs *A* and *B* which will require a given condenser to work through a reasonably full range while regulating the secondary bus voltage. In this way the high-voltage system is given the benefit of as much correction as the capacity of the particular condenser will permit, but without sacrificing the main function of secondary bus regulation.

One of the first examples of this type of application was that installed at the Howard substation as shown in figure 7. Here the condenser rating of 15,000 kva was chosen by bank capacity and for other reasons, and it was desired to give the 132-kv system the full benefit of the condenser output while regulating the 66-kv bus. This was particularly important in this case in order to help supply the flow of reactive kilovolt-amperes required between Howard and Canton, the latter being a low-voltage point on the system because of previously installed transformers rated at 120 kv. Here, the division between *A* and *B* is in the proportion of 57 per cent to 43 per cent of the total reactance from primary to secondary which falls within the manufacturer's tolerance on a specification calling for a 60 per cent and 40 per cent division.

The operating results with this setup have been satisfactory and the condenser is still holding good voltage on the 66-kv system, although with the present heavier 132-kv system power flow, which was not altogether foreseen at the time of the installation, it would have been better to have placed the condenser a little closer to the 66-kv bus. On the other hand, this defect has been fully compensated by a subsequent installation of a much larger synchronous condenser on the 132-kv system at an adjacent station (Fostoria), which will be described later under four-winding transformers.

The use of this type of three-winding transformer is not confined to instances where the secondary voltage is too high for synchronous-condenser operation. Figure 8 shows the Carbondale substation and the equivalent connected 22-kv system of The Scranton Electric Company, where it was desired to regulate the 4-kv bus and at the same time to provide as much correction as possible for the 22-kv system. Here a 5,000-kva synchronous condenser, which is much larger than would have been necessary for regulating directly on the 4-kv bus, is used effectively by connecting it to the 4-kv tertiary winding of a 3-winding transformer bank. Figure 9 shows an analysis, confined to the transformer circuit alone, which was made prior to this installation to show a comparison between the condenser capacity required to overcome the transformer drop under a given load, first, with the condenser directly on the 4-kv bus and, second, with the condenser on the tertiary winding of a three-winding bank of the design shown in figure 10. Of course, the comparison shown here was not quite complete because of the omission of the system impedance back of the 22-kv bus. Actually, the difference between the condensers required in the two setups would be somewhat less due to the effect of this difference in condenser capacity on the system impedance, as brought out in the discussion of figure 1.

This installation has been in operation for some time and approaches flat regulation for both 4-kv and 22-kv bus voltages.

It is possible in certain cases to obtain the advantages of the type II three-winding transformer design by adding an external reactor to an existing two- or three-winding transformer bank. In the Suburban plant setup, shown in elementary form in figure 11, it was desired to install a synchronous condenser to regulate the 4-kv distribution bus, but at the same time to furnish the maximum amount of much needed reactive kilovolt-ampere correction to the 22-kv and 66-kv systems. This result was made possible by installing the 10.8 per cent reactor, shown as leg *B* in figure 11, and connecting the synchronous condenser to an auxiliary 4-kv bus connected directly to the terminals of the transformer bank. This scheme not only made it possible to deliver practically double the amount of reactive correction to the 66-kv system but also reduced the short-circuit problem on the 4-kv distribution bus. To make the scheme adjustable, both for present as well as future requirements, taps were provided in the reactor.

Other notable installations of type II three-winding transformers with synchronous condensers are now under construction and will be placed in operation during the present year at Torrey substation at Canton, Ohio, and at New Carlisle substation near South Bend, Indiana. The former is a 30,000-kva transformer-bank installation, and the latter, 45,000 kva.

Type III—Three-Winding Transformer Design With Condenser Regulating Primary Voltage

In this type of three-winding transformer design, the equivalent reactance network is such that the condenser is connected electrically close to the high-voltage winding and therefore is capable of effectively regulating the high-voltage bus only. In other words, leg *A* in the equivalent network is small with respect to *B*. A typical elementary diagram is shown in figure 12 where the values used correspond to those of figures 3 and 6. Obviously, such a set-up does not provide a practical means of regulating the secondary bus voltage since large swings in primary voltage and a very large condenser would be required in order to compensate the drop through leg *B* of the transformer. It might be used, however, where it is desired to maintain constant voltage on the high-voltage bus, and by providing separate means, such as automatic tap changing under load, for regulating the secondary bus.

No setups of this type involving three-winding transformers and synchronous condensers are in operation on the American Gas and Electric Company system, although the four-winding transformer installations described below are similar in performance and purpose to this type.

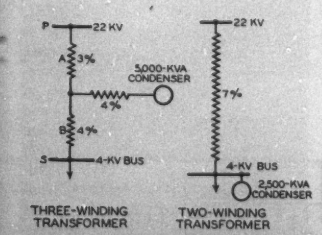

Figure 10. Equivalent networks of three-winding and two-winding transformers used for comparison in figure 9

Special Four-Winding Transformers With Synchronous Condensers or Generators for Regulating More Than One Bus Voltage

In 1935 a proposed synchronous-condenser application together with a new transformer bank to be installed at the Fostoria substation presented a somewhat unusual regulating problem. An existing installation of a 20,000-kva three-winding transformer bank, stepping down from 132 kv to 66 kv with a tertiary winding operating two 5,000-kva synchronous condensers, was totally ineffective for regulating the 66-kv bus because the transformer design was type III instead of type I. The existing transformer bank was fortunately quite suitable for use at another location where additional capacity without synchronous condensers was needed. In replacing this bank it was desired to provide for the operation of a large synchronous condenser to maintain bus voltage on the 132-kv system, and at the same time it was necessary to provide some means of regulation for the 66-kv bus.

The first plan proposed for this job was to use a type III three-winding transformer bank with load-ratio-control in the 66-kv winding, and to transfer the two 5,000-kva condensers to some other location. The plan finally worked out, however, made use of a four-winding transformer, designed along the lines shown in figures 13 and 14. The two 5,000-kva synchronous condensers were connected to a fourth winding so placed with respect to the other windings that effective regulation of the 66-kv bus could be obtained at the same time that the large condenser was regulating the 132-kv bus. As shown in figure 14, which represents an approximation of the equivalent reactance network of the four-winding transformer bank, the electrical effect is simply as though the large condenser were connected directly on the 132-kv bus and the two small condensers directly on the 66-kv bus. While the rigorous representation of the reactance network of a four-winding transformer bank involves a complicated solution such as that worked out by F. M. Starr,[6] the actual diagram did not differ greatly from the simple straight-line equivalent circuit shown in figure 14 and produced by an arrangement of windings on the transformer core as shown in figure 13. The transformers were specified, designed, and purchased to meet approximately the equivalent-reactance circuit of figure 14.

For regulating the 132-kv bus, there was purchased a synchronous condenser having a continuous rating of 36,000 kva at 15 pounds hydrogen pressure, and provided with sufficient excitation voltage and capacity to give a short-time ceiling overload rating of 75,000 kva.

Since the two 5,000-kva condensers were built for 4,000-volt operation, whereas a rating of 11,000 volts was chosen for the new condenser, a con-

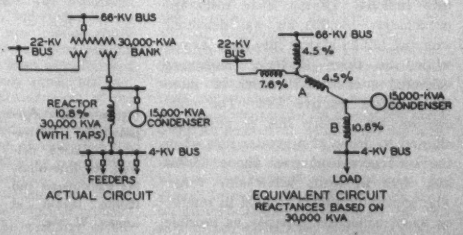

Figure 11. Simulation of type II transformers by adding reactor between load and condenser—Suburban plant, Scranton, Pa.

venient incidental feature of the four-winding transformer design was the use of the 4,000-volt condenser winding for starting the large machine, thus eliminating the necessity for compensator

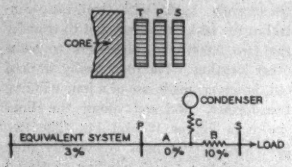

Figure 12. Probable arrangement of windings and typical application of type III three-winding transformer with condenser regulating high-voltage system only

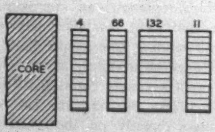

Figure 13. Winding arrangement for four-winding transformers, Fostoria, Ohio

or starting taps. Besides furnishing about the right voltage for starting purposes, this arrangement, with the two 5,000-kva condensers running while starting the large machine, offered the additional advantage of supplying a large part of the starting kilovolt-amperes directly, thereby reducing the disturbance on the system.

The performance of this installation has been eminently satisfactory, both from the standpoint of the 132-kv system regulation and the 66-kv bus regulation. One 5,000-kva condenser has been sufficient much of the time for maintaining 66-kv bus voltage. Some time after this installation was completed there was staged a test to determine the ability of the 132-kv system, together with this condenser installation, to handle heavy emergency power flow into Indiana. During these tests approximately 150,000 kw was delivered over the 132-kv system into Fort Wayne while the three Fostoria condensers delivered a combined output of more than 60,000 reactive kva. The voltage on the 132-kv bus is purposely allowed to droop at a greater rate when the condenser load goes above 36,000 kva than at loads below this value. The reason for this is to hold in reserve as much condenser capacity as possible and for as long a time as possible before the output of the machine is automatically cut back because of excessive field temperature. The inherent droop in the electronic regulator is approximately one per cent from zero to 30,000 kva on the condenser, with an additional droop of between three per cent and four per cent in going from 30,000 to 75,000 kva.

A more recent and somewhat larger four-winding transformer bank, having some of the same characteristics as that at Fostoria, was designed and installed for use with the high-pressure superposition turbine at Logan, W. Va. The elementary diagram showing the approximate reactance relationships between the four windings of this bank and the adjacent system connections is shown in figure 16. The relative arrangement of windings is shown in

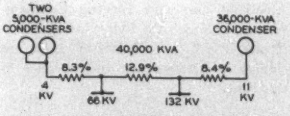

Figure 14. Approximate equivalent reactance network for Fostoria four-winding transformers

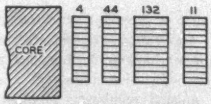

Figure 15. Winding arrangement for four-winding transformer, Logan, W. Va.

figure 15. It will be noted that the 50,000-kva generator is connected in effect close to the 132-kv bus and is arranged to maintain voltage on that bus. The two 18,750-kva generators are connected directly through step-up transformers to the 44-kv bus, and the three small machines on the 4-kv winding are coupled fairly close to the 44-kv winding but remote from the 132-kv and 11-kv windings. In this setup the 44-kv bus voltage is controlled by means of the two 18,750-kva generators, while the three small machines are expected to operate without regulation and with a fixed field setting near unity power factor to obtain maximum kilowatt output from the generators. The 50,000-kva machine regulates voltage on the 132-kv bus through the use of a resistance-reactance compensator in conjunction with the generator terminal voltage and the load delivered to the transformer.

This installation has worked out entirely satisfactorily in performing the regulating functions for which it was designed. As in the case of the Fostoria transformer bank, the rigorous equivalent reactance network of the transformer bank would be somewhat more complicated but the coil arrangement and approximate reactances specified and obtained for the bank gave very nearly the straight-line reactance diagram shown in figure 16. A photograph of one unit of this transformer bank is shown in figure 17.

Conclusions

It will be seen from the above descriptions of actual installations on the American Gas and Electric Company system that three-winding and four-winding transformers properly designed have become a rather important tool for use in our system planning. In any large interconnected network such as this, having many important load and generating points, with a wide variation both in direction and amount of power flow, it is becoming increasingly necessary to operate to a large extent at fixed voltage levels throughout the system. Of course, a certain amount

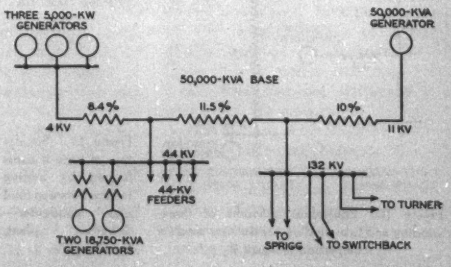

Figure 16. Approximate equivalent reactance network for four-winding transformers and station layout at Logan, W. Va.

of voltage gradient is always necessary to keep within economic limits of synchronous-condenser capacity but these voltage gradients are not allowed to become extreme. Important generating stations maintain a voltage of approximately five per cent above the nominal 132-kv level, while the low points on the system, with one or two exceptions, do not fall below 132 kv. Under these conditions, heavy power flow in any given direction for any considerable distance necessarily involves leading power factor, that is, a reverse flow of reactive kilovolt-amperes, most of which must be supplied by synchronous condensers. The special designs of three-winding and four-winding transformers described herein have contributed very substantially to the solution of the problem of maintaining reasonably constant voltage levels under these conditions of operation on the 132-kv system. In addition a number of regulating problems on lower-voltage systems have been efficiently handled by their use.

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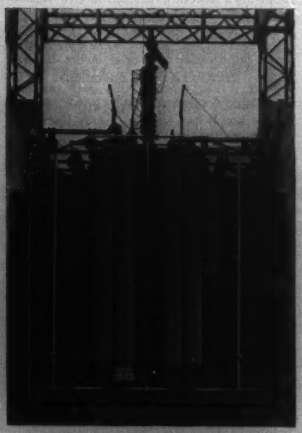

Figure 17. One unit of 100,000-kva four-winding transformer bank at Logan, W. Va.

Discussion

Wm. R. Brownlee (The Commonwealth and Southern Corporation, Jackson, Mich.): The concept of an equivalent system reactance against which a change in reactive kilovolt-amperes on a synchronous machine operates is almost indispensable for intelligent planning or even for best operation of interconnected synchronous equipment. Many have unquestionably used it in some form without a thorough understanding of the principles which have been so clearly illustrated by the author. He is to be congratulated on the clearness with which he has reduced the handling of reactive kilovolt-amperes to simple terms, and for securing valuable system characteristics at little or no increase in capital expenditure through proper advance planning.

Naturally the concept of a change in reactive kilovolt-amperes at one point of a system operating upon its equivalent reactance is based on the assumption that the resulting redistribution of reactive kilovolt-amperes between various machines will not cause any of them to reach their operating limits. This will usually be true in practical problems, but the incremental reactive-kilovolt-ampere values which are readily given by a calculating board or analytical study (necessary to determine the equivalent system reactance) will provide a simple check. In case the ability of any machine is exceeded, its connection on the calculating board may be removed from the supply bus (or common bus when considering tap changes). Results will include the variation in voltage on the "regulated" bus where the limits of machine abilities are reached.

A useful corollary of this principle is that a change in reactive kilovolt-amperes or a transformer tap change on an interconnected system will not cause any incremental flow of reactive kilovolt-amperes over any line or impedance branch which directly joins two regulated busses (assuming the machine abilities are not exceeded). Accordingly, such branches may be omitted in arriving at equivalent system reactance.

L. H. Hill (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): One of the noticeable trends in transformer design and application during the past few years has been the increased number of multiwinding transformers. Not so many years ago a three-winding transformer was considered comparatively unusual, but today three-winding transformers are comparatively common. The number of four-winding transformers that have been actually used so far has been relatively small, but Mr. St. Clair has ably indicated some of the applications for this type of transformer.

It might be interesting to point out from the manufacturing point of view that the construction of a four-winding transformer introduces no great technical difficulties. As far as the electrical design of the transformer is concerned, the principal problem consists in arranging the windings to obtain the desired reactances. In the case of core-type transformers generally used in the smaller sizes, the number of possibilities is limited due to the fact that it is usually desirable to use concentric windings. In the larger sizes, however, where the shell type of construction is frequently used, the windings can be grouped so that almost any combination of reactances may be obtained without sacrificing other desirable characteristics in the transformer. Having made an electrical design to suit the reactances desired, the only remaining added complications to the ordinary transformer are the greater number of bushings required and the greater number of terminal boards needed. In smaller sizes of transformers it may be difficult to obtain the necessary clearances for terminal boards and bushings without resorting to a tank larger than necessary, but in the larger sizes the necessary space is usually available.

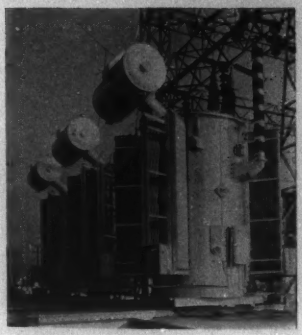

Figure 1

Mr. St. Clair describes an installation of four-winding transformers at the Fostoria substation, and figure 1 of this discussion illustrates three of the transformers before the spare unit had been installed. The complete rating is as follows:

High voltage 13,333 kva, 138 kv
Second voltage 6,667 kva, 69 kv } single phase, 60 cycles
Third voltage 12,500 kva, 11 kv
Fourth voltage 4,000 kva, 4 kv

H. P. St. Clair: Mr. Hill mentioned some of the principal problems which have to be met and solved in the design, construction, and assembly of multiwinding transformers.

In regard to the problem of arranging the windings to obtain the reactances desired, we have made it a point to co-operate closely with the designers by making available to them as much flexibility as possible without sacrificing the main regulating function which is desired in a particular application. In this way, we have tried to avoid penalizing the transformer design from the standpoint of cost because of the reactances requested. In a very few cases a certain amount of penalty in cost may have been unavoidable, but, if so, the improved over-all operating results obtained were worth the small additional cost. In general, however, it is possible to work out a satisfactory design to accomplish the desired results without any increase in cost.

Wave Shape of 30- and 60-Phase Rectifier Groups

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FELLOW AIEE

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MEMBER AIEE

AS pointed out in a number of recent papers,[1,2] a mercury-arc rectifier draws a distorted current from the a-c supply system, even though power to the system is supplied by a sine-wave source. The harmonics in the current wave react on the supply system to cause distortion in the voltage wave, the degree of distortion being a function of the rating of the rectifier, the number of phases in which power is supplied to the anodes, the impedance at harmonic frequencies of the supply system, and the rectifier load. It is well known that, in theory at least, reductions in the wave-shape distortion may be effected by increasing the number of rectifier phases and thus reducing the number of harmonic components present in the supply-circuit current.[1,2] Up to 1937, however, because of practical difficulties, largely in the design of the complex transformer arrangement required, no attempts were made to produce rectifiers commercially having more than 12 phases.

Recently the Aluminum Company of America installed rectifiers having a total capacity of 82,500 kilowatts for conversion of alternating to direct current in its plants at Alcoa, Tenn., and Massena, N. Y.[3] These are the largest installations of rectifiers supplied from overhead transmission systems in this country at the present time. The power supply at both Alcoa and Massena may be interconnected with several high-voltage networks, which in turn supply several power distribution systems involved in exposures with open-wire telephone lines. Cooperative studies were made to determine the effects of these rectifiers on the wave shape of the a-c supply systems and the telephone-circuit noise. These studies were carried on during 1937 and 1938, and included preliminary estimates of the harmonic components arising in the rectifiers and their effect on the power-system wave shape. The estimates indicated that the operation of the rectifiers could be expected to increase the inductive influence of the power-supply networks over the area affected, with resultant increases in the telephone circuit noise. Tests made after half of the rectifiers were in operation at Alcoa confirmed the results of the estimates and indicated the necessity for a reduction in the rectifier harmonics.

Because of the size of these installations, and the complexity of the supply systems, it appeared impracticable to limit the rectifier harmonics by the use of frequency-selective devices, which have been successfully applied to certain smaller installations.[1] However, theoretical considerations and tests on a miniature rectifier set simulating the electrical characteristics of the converters under consideration, indicated that substantial reductions in the wave-shape distortion might be effected through the use of a relatively simple installation of phase-shifting transformers. Following the successful application of this idea in the case of the miniature rectifiers, a set of full-sized phase-shifting transformers was built and applied to each group of five 5,500-kw rectifiers at Alcoa. This arrangement reduced the important harmonic components on the power-supply systems to relatively small values, and restored the wave shape and noise conditions practically to normal. This paper describes briefly the voltage and current relations, the preliminary tests on the small-scale rectifier equipment, the phase-shifting transformers and their application to this particular situation, and presents data to indicate their effectiveness.

Harmonics in Power Supply to Multiphase Rectifiers

A number of different transformer connections[4] are used to secure six-phase operation of a rectifier when supplied from a three-phase source. For all of these connections there is a 60-degree phase relation between the fundamental-frequency voltages applied to anodes which fire consecutively, and the lowest-order harmonic component appearing in the d-c voltage wave is the sixth (360 cycles for a 60-cycle supply system). The corresponding components in the a-c supply are the fifth and seventh harmonics (300 and 420 cycles). All harmonics of order $(6a \pm 1)$, where a is any positive integer, appear in the a-c supply.

In order to increase the number of phases beyond six, it is necessary to ar-

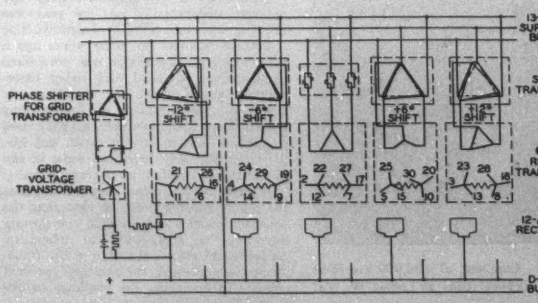

Figure 1. Schematic diagram of transformer connections in 30-phase rectifier station

Notes:

1. Connections shown for only one six-phase secondary on each rectifier transformer. Actually in each transformer there are four groups of secondaries operated in parallel supplying a total of 24 anodes in two rectifier tanks
2. Numbers on transformer secondaries indicate firing order of anodes in the five-unit station (30-phase operation)
3. Dotted Δ of phase-shifting transformers indicates supply-bus voltage; heavy lines refer to voltages applied to rectifier transformer primaries

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O. K. MARTI is engineer in charge of rectifier design, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.; T. A. TAYLOR is a member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y.

Acknowledgment is made to the Aluminum Company of America and to the various power and telephone companies co-operating in the field tests at Alcoa, Tenn., and Massena, N. Y.

1. For all numbered references, see list at end of paper.

Table I. Theoretical Relationships in Multiphase Rectifiers

Equivalent Number of Rectifier Phases	Phase Relation Between Fundamental-Frequency Voltages Applied to Anodes Which Fire Consecutively (Deg)	Lowest Order Harmonic in D-C Output	Lowest Order Harmonic in A-C Supply
6	60	6	5, 7
12	30	12	11, 13
18	20	18	17, 19
24	15	24	23, 25
30	12	30	29, 31
36	10	36	35, 37
48	7.5	48	47, 49
60	6	60	59, 61

range the rectifier transformer connections so that the phase angle between the fundamental-frequency voltages applied to two anodes which fire consecutively is less than 60 degrees. One method of accomplishing this is by multiple connection of secondary windings associated with a single primary. The delta zig-zag connection for 12-phase rectifiers is one example of this method. Twelve-phase operation may also be secured by operating two 6-phase rectifiers in parallel, with the primary of one transformer connected delta and the second in wye. In either case the phase relation between the fundamental-frequency voltages applied to corresponding anodes of the two units is 30 degrees. Theoretically, the lowest-order harmonic in the d-c circuit voltage is then the 12th (720 cycles) appearing as 660 and 780 cycles on the a-c side. Similarly, if it is possible to operate a larger number of 6-phase rectifiers in parallel, and to provide the proper phase displacement between the fundamental-frequency voltages applied to the corresponding anodes of the different rectifiers, the number of phases can be increased, together with the order of the lowest harmonic appearing in the d-c output and a-c supply to the station, as shown in table I.

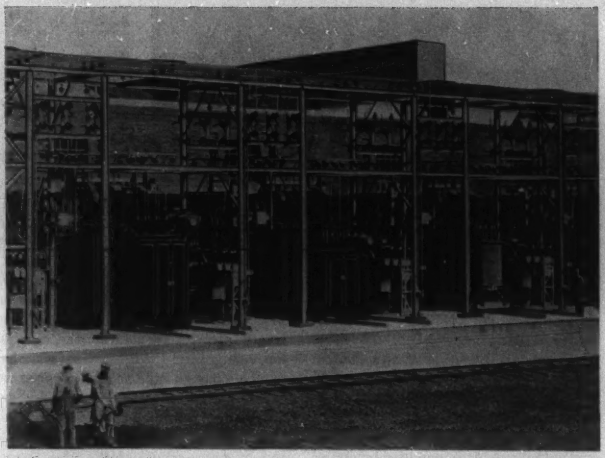

Figure 3. Rectifier transformers, phase-shifting transformers, and reactor

Thirty-Phase Operation at Alcoa and Massena

The rectifiers installed at Alcoa are divided into two stations, each having a total d-c output of 27,500 kw. Each of these stations includes five rectifier transformers, and each transformer, having two double six-phase secondaries, supplies two 12-anode rectifier tanks. All secondaries are connected in double wye with interphase transformers. Each unit (one transformer and two rectifier tanks) is rated at 5,500 kw. Referring to figure 1, in the first station three of the five rectifier transformers have delta-connected primaries, while the primaries of the other two transformers are wye-connected. The second station at Alcoa, as well as the station at Massena, has three units with wye-connected primaries and two with delta-connected primaries. In all three stations four of the units are connected to the supply bus through phase-shifting transformers and one through a reactor.

In figure 1, the connections of the grid-control circuit for regulating the firing of the anodes, and as a consequence the d-c circuit voltage, are shown only for unit 1.

The vector diagram of figure 2*A* shows the 30-degree phase relation between the fundamental-frequency voltages applied to corresponding anodes of a wye-connected and delta-connected unit, and the adjoining curves illustrate the wave forms of the currents between the supply bus and these units without the phase-shifting transformers. The resultant current

Figure 2. Phase relation between fundamental-frequency voltages applied to corresponding anodes of five units of figure 1 and currents from 13-kv bus to individual units

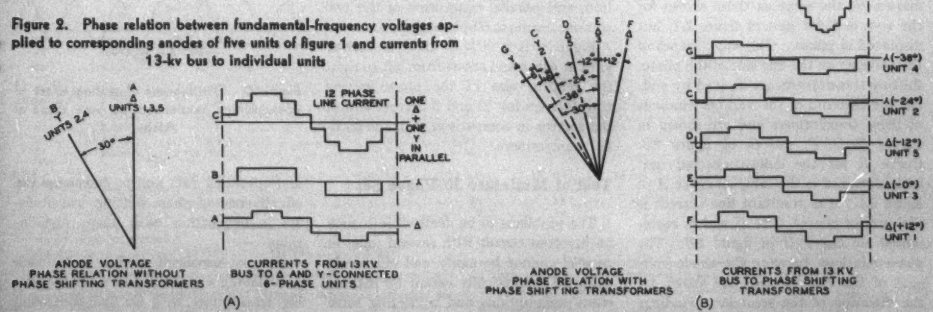

Figure 4. Miniature test set simulating 30-phase system

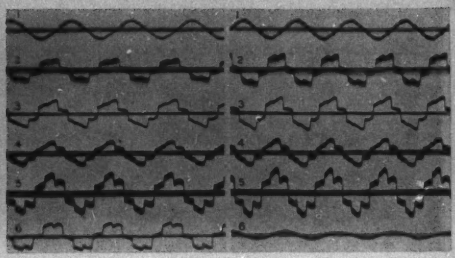

Figure 5. Oscillograms illustrating effect of phase-shifting transformers on currents to each unit in miniature tests

1—Resultant line current
2—Wye unit (−6 degrees shift)
3—Wye unit (+6 degrees shift)
4—Delta unit (−12 degrees shift)
5—Delta unit (no shift)
6—Delta unit (+12 degrees shift)

A—Five units in service
B—Four units in service

flowing in the supply circuit, to which these two rectifier units are directly connected, and in case no other converting device is connected to that circuit, is the sum of the currents represented by curves *A* and *B* as shown in curve *C*. (As will be shown later, the wave shape of these currents is not as simple as indicated in this diagram due to other factors, such as resistance, inductance, arc drop, exciting currents of transformers, wave shape of the supply-bus voltage, etc.) The phase-shifting transformers are connected as autotransformers ahead of four of the rectifier transformers, as shown in figure 1. A positive phase shift of 12 degrees is consequently introduced ahead of one of the delta-connected units, with a corresponding negative shift ahead of a second delta unit. Positive and negative phase shifts of six degrees are introduced ahead of the two wye units. As shown in the vector diagram, figure 2*B*, the fundamental-frequency voltages applied to corresponding anodes of the five units are now 12 degrees apart, and consequently the equivalent of 30-phase operation is obtained, in accordance with the relationships of table I. The wave shapes of the currents between the phase-shifting transformers and rectifier-transformer primaries are the same as those shown for the wye or delta unit of figure 2*A*, but displaced in phase. The wave shapes of the currents on the line side of the phase-shifting transformers are derived by adding the currents in the various windings of these transformers and are shown in curves *C*, *D*, *F*, and *G*, of figure 2*B*. Curve *E* for the delta-connected unit with a reactor is the same as curve *A* of figure 2*A*. The resultant line current is the sum of curves *C* to *G* and is represented by curve *H* in figure 2*B*. The phase relations, between the anode voltages of the various units are shown by the direction of the secondary windings in figure 1, together with the firing order. The dotted lines of the phase-shifting transformer vectors indicate the supply-bus voltage, and the heavy lines give the relative phases of the voltages applied to the rectifier-transformer primaries.

Different types and sizes of phase-shifting transformers are supplied for 6- and 12-degree phase shift. The transformers for positive and negative phase shift are identical except for some of their internal connections. Both sizes of transformer are designed to have equal reactances of approximately one per cent based on the rating of the rectifier transformer. A three-phase reactor is connected ahead of the unit requiring no phase shift to compensate for the drop in the other units. This reactor was introduced in order to avoid all possible sources of harmonics from unbalances, due to the angle between voltages not being exactly 30 degrees, or the magnitudes of the voltages and the firing period of the anodes not being equal. In the case of the other stations at Alcoa and Massena, where there are three wye-connected and two delta-connected units, the same arrangement is used, except that two wye-connected units are shifted by plus and minus 12 degrees, while the delta units are shifted plus and minus 6 degrees. With this arrangement the anode voltages in the second station at Alcoa are shifted by 6 degrees from those in the first station, and parallel connection of the two stations results in 60-phase operation.

Figure 3 is a view of the transformer yard at Alcoa and shows from left to right the relative size of the phase-shifting transformers for 12 and 6 degrees and of the reactor in comparison with the rectifier transformers.

Test of Miniature 30-Phase Set

The problems to be dealt with in such an involved circuit with several units in parallel cannot be easily and effectively analyzed theoretically except by making many assumptions and neglecting some of the factors. Such an analysis requires a great deal of time and the results are subject to an element of uncertainty, especially in view of the fact that the voltages and currents involved are not of sinusoidal wave shape. For this reason a model 30-phase rectifier test set (see figure 4) was built in order to obtain as quickly as possible the necessary design and operating data and to determine the effectiveness of phase-shifting transformers in connection with these installations.

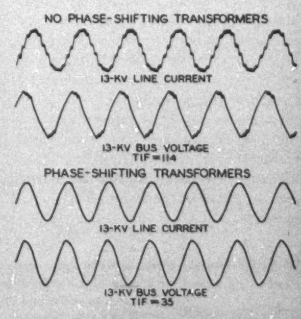

Figure 6. Oscillograms illustrating effect of phase-shifting transformers on wave shape at Alcoa

The set consisted of five units, each unit having a rectifier and a phase-shifting transformer with six grid-controlled

tubes. In other words, each unit of six tubes was comparable to a six-anode rectifier, whereas in the field 12-anode rectifiers are used with two anodes operating in parallel. A polarization voltage simulating the back electromotive force due to the electrolytic cells was provided on the d-c side. The constants or characteristics of the transformers and reactors, although small-scale models were used, were such that representative conditions as to the circulating currents between wye and delta units, resistance and reactance drop, etc., were obtained.

Since very little power was required, the study of the wave shapes with oscillograph and wave-shape analyzer for different system and load characteristics could be carried out very easily and with the greatest convenience. Some of the results obtained with this set are shown in the oscillograms of figure 5*A* and *B*. The lower curves of figure 5*A* show the primary currents in one phase of each of the five units (three delta and two wye), and the top curve is the resultant current of the same phase of the 30-phase system. It will be noted that the latter approaches much more closely a smooth sine wave. A comparison may be made with the curves of figure 2*B* which are arranged in the same order as the oscillographic traces, and the effect of the phase-shifting transformers can be easily analyzed. The trace of the primary current of the last unit is somewhat distorted due to the presence of an abnormally high reactance in the circuit.

Figure 5*B* shows the result of the same setup but with one unit taken out of service. The resultant of the primary current of the four units is somewhat distorted under this condition when compared to the top curve of figure 5*A*. However, the four units still shared the load very satisfactorily. The last trace of figure 5*B* shows the magnetizing current in the primary of the transformer, the cathode of this unit being disconnected. Many other circuit arrangements were studied, taking several units out of service and adding a sixth unit with delta or wye connection to the setup. Furthermore, the influence of delaying the firing of the anodes by means of grid control was investigated and its effect on the shape of the resultant supply bus current observed.

Effectiveness of Phase-Shifting Transformers

According to the relationships of table I, the 30-phase connection should eliminate all harmonics in the a-c supply to the rectifier station below the 29th (1,740 cycles). Complete elimination of these harmonics is not realized in practice, due to slight inequalities in the loads on the rectifier units and in the impedance of the rectifier transformers and associated bus structure, and also on account of difficulties in securing exactly the proper phase relationship between the various anode voltages. However, as indicated in table II, the measured reductions in harmonic current for 30-phase operation compared with straight 6-phase operation, range as high as 90 to 1, with the greatest reductions at the lower frequencies, which are present in the largest magnitudes for 6-phase operation. The $I \cdot T$ product,[5] which is an index to the weighted harmonic content of the alternating current, is reduced by as much as 18 to 1 through the use of the phase-shifting transformers.

The improvement in 13-kv line-current and bus-voltage wave shape resulting from the use of the phase shifters is graphically illustrated by the oscillograms of figure 6. The first two traces were obtained immediately after the first rectifier station at Alcoa was placed in operation and before the installation of the phase-shifting transformers. The two lower traces were obtained with the

Table II. Effectiveness of 30-Phase Connection in Reducing Harmonic Currents From 27,500-Kw Rectifier Station Showing Effect of Grid Control†

Harmonic n	Frequency	"Equivalent 6-Phase Operation" Arithmetic Sum of Harmonic Line Currents in Rectifier Units 1, 2, 3, 4, and 5 (Amperes)			"Equivalent 30-Phase Operation" Vector Sum of Harmonic Line Currents (Total Current to Station) (Amperes)			Effectiveness of 30-Phase Connection as Compared With 6-Phase Operation**		
		No Grid Control	Balanced Loads*	5 Per Cent Control	No Grid Control	Balanced Loads*	5 Per Cent Control	No Grid Control	Balanced Loads*	5 Per Cent Control
5	300	266.0	262.0		8.0	5.0		33.0	52.0	
7	420	105.0	101.0		7.9	8.5		13.0	13.0	
11	660	70.5	72.0	78.7	0.79	1.08	2.32	89.0	66.0	34.0
13	780	49.8	47.5	47.5	0.555	0.51	1.7	90.0	94.0	28.0
17	1,020	25.9	26.9	42.5	0.39	0.93	1.9	66.0	29.0	23.0
19	1,140	21.3	23.8	27.1	0.31	0.85	1.4	69.0	28.0	20.0
23	1,380	8.5	9.6	24.7	0.97	0.33	2.6	8.8	29.0	9.4
25	1,500	8.3	10.0	18.2	0.96	1.21	1.4	8.6	8.2	13.0
29‡	1,740	4.96	4.8	13.8	4.85	4.45	13.7	1.02	1.08	1.01
31‡	1,860	4.71	3.9	10.9	4.6	3.6	10.9	1.03	1.08	1.0
35	2,100	4.83			0.57			8.6		
37	2,220	5.03			0.88			5.7		
41	2,460	3.56			0.18			19.7		
43	2,580	3.58			0.17			20.9		
47	2,820	2.29			0.15			15.1		
49	2,940	2.35			0.16			14.4		
53	3,180	1.68			0.41			4.1		
55	3,300	1.65			0.30			5.6		
59‡	3,540	1.29			1.21			1.07		
61‡	3,660	1.23			1.08			1.14		
65	3,900	0.95			0.34			2.85		
67	4,020	1.19			0.45			2.65		
$I \cdot T$§		480,000	505,500	659,000	29,600	28,100	78,000	16.2	18.0	8.4
13-kv rectifier bus voltage TIF§					45	38	112			
154-kv bus voltage TIF§					8	10	13			
D-c bus voltage		600	605	575						
Total d-c output current (amperes)		40,000	39,200	35,000						

* Small amount of grid control on certain units to balance d-c output currents.

** Expressed as ratio of arithmetic sum of harmonic currents in individual rectifiers to vector sum of corresponding current.

† These frequencies not suppressed by 30-phase operation.

‡ Measured at Alcoa on station with three delta and two wye units.

§ See reference 5.

same rectifier loads and supply system arrangement after the installation of the phase shifters.

The phase-to-neutral impedances of the 13-kv supply system, looked at from the primaries of the phase-shifting transformers, as calculated from the harmonic voltages and currents for the system arrangement under which the data of table II were obtained, are as follows:

Frequency	Phase-to-Neutral Impedance (Ohms)
660	5.6
780	6.7
1,020	4.2
1,140	3.1
1,380	7.8
1,500	8.3
1,740	13.6
1,860	11.1

The commutating reactance of the rectifier transformers is approximately six per cent.

Effect of Grid Control on 30-Phase Operation

Included in table II are the results of tests to determine the effect on the a-c wave shape of reducing the d-c bus voltage by the use of grid control.[3,6] The use of only a small amount of control on certain units to balance the d-c load among the units makes no substantial change in the over-all effectiveness of the phase-shifting transformers. However, with grid control used to reduce the d-c bus voltage in the order of five per cent, the over-all effectiveness of the 30-phase arrangement is somewhat impaired, as indicated by an increase of about 3 to 1 in the $I \cdot T$ product. Even under this condition, the 30-phase arrangement is about eight times better than straight six-phase operation with the same amount of grid control, and the reductions at four important frequencies (660, 780, 1,020, and 1,140 cycles) are 20 to 1 or more.

Vector Relations Between Harmonic Line Currents

The effectiveness of the 30-phase connection in reducing the harmonics out of the rectifier station depends upon the balance of five nearly equal currents in the proper phase relation. This is illustrated in figure 7*A* which shows the measured vector relations between the 780-cycle line currents to the five rectifier units of figure 1. These currents were measured on the line side of the phase-shifting transformers. The phase angles were obtained from measurements of sums and differences of the harmonic voltage drops across inductive shunts in the secondaries of the current transformers associated with each unit. It is evident from the diagram that the five vectors are nearly equal and approximately 72 degrees apart. The resultant of the five vectors is also shown. The reduction factor of 89.5 is the ratio of the arithmetic sum of the five currents to the vector sum or the resultant current.

Figure 7. Measured vector relations between harmonic line currents to five rectifiers equipped with phase-shifting transformers for 30-phase operation as shown in figure 1

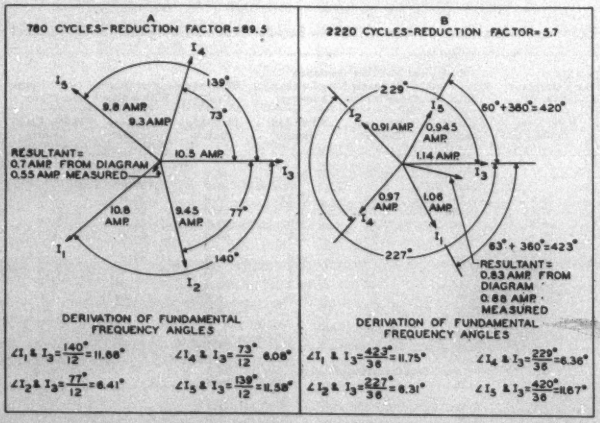

Table III. Effect of "Balanced" and "Unbalanced" Rectifier Operation†

Ratio of Harmonic Currents With 6-Phase Operation to Those Measured With 30-Phase Operation

Frequency	Five Units in Parallel "Balanced Rectifiers"*	Four Units in Parallel*
300	51.5	5.9
420	27.0	4.5
660	43.7	3.7
780	35.7	3.8
1,020	29.0	3.0
1,140	42.0	3.9
1,380	22.9	2.2
1,500	28.2	2.7
1,740‡	0.95	1.01
1,860‡	0.92	1.05
2,100	6.2	
2,220	5.8	
2,460	23.5	
2,580	38.2	
2,820	24.0	
2,940	16.2	
3,180	6.3	
3,300	3.9	
3,540‡	1.12	
3,660‡	1.19	
3,900	3.5	
4,020	3.8	
$I \cdot T$ (ratio)	15.9	3.2
$I \cdot T$ (6 phase) magnitude	449,000	330,000
$I \cdot T$ (30 phase) magnitude	28,300	104,000
Voltage TIP (13-kv rectifier bus)	29.0	69.0

† Measured at Massena on 27,500-kw station with three wye and two delta units.

‡ These frequencies not suppressed by 30-phase operation.

* Same total d-c load in each case.

Since 780 cycles (13th harmonic) appears in the a-c supply as a result of the 12th harmonic in the d-c wave, the phase shift of the various 780-cycle currents from that in unit 3 (taken as reference) should be 12 times the fundamental-frequency shift introduced by the phase-shifting transformers. The derivation of the fundamental-frequency angles from the measured angles is shown in figure 7*A*. The derived values are fairly close to the theoretical 6- and 12-degree shifts.

A similar diagram for the 37th harmonic is shown in figure 7*B*. In this case the phase shift is 36 times that at the fundamental frequency. The fundamental-frequency shifts derived from the measured angles are about the same as those derived from the 780-cycle diagram. However, the effects of the small deviations from the correct shifts of 12 and 6 degrees tend to become greater for the higher-order harmonics, and the angles between the five vectors in figure 7*B* no longer closely approximate 72 degrees. The reduction factor is only 5.7 compared with 89.5 at 780 cycles.

Table IV. Effect of Phase-Shifting Transformers on Supply-System Voltage Wave Shape and Telephone Circuit Noise (for 27,500-Kw Station in Operation at Alcoa)

	Rectifiers Off	Five Units* No Phase Shifters	Five Units Phase Shifters**
Power System A		**Voltage TIF**	
Alcoa 13-kv rectifier bus	10	176	40
Alcoa 154-kv bus	10	77	15
Location 1 on 154 kv	9	64	7
2 on 154 kv	12	118	13
3 on 154 kv	29	480	34
4 on 154 kv	16	84	14
		Maximum Noise on Exposed Toll Circuits	
Decibels above reference noise	37	57	37
Noise units	500	5,000	500
Power System B		**Voltage TIF**	
Alcoa 13-kv rectifier bus	10	79	14
Alcoa 120-kv bus	10	51	10
Location 5 on 120 kv	15	56	21
6 on 120 kv	9	23	12
7 on 66 kv	14	33	24
		Maximum Noise on Exposed Toll Circuits	
Decibels above reference noise	32	44	35
Noise units	280	1,100	400
Power System C		**Voltage TIF**	
Alcoa 13-kv rectifier bus	10	137	
Alcoa 154-kv bus	14	233	16
		Maximum Noise on Aluminum Company Telephone Circuits	
Decibels above reference noise	42	73.5	42
Noise units	900	33,000	900

* Equivalent to one 12-phase rectifier of 22,000 kw and one 6-phase rectifier of 5,500 kw in parallel.

** "Balanced operation."

"Balanced" and "Unbalanced" Operation

From the vector diagrams of figure 7 it may be seen that the effectiveness of the 30-phase method of operation is impaired if one of the units is shut down. If the load on the four remaining units is unchanged, the resultant harmonic current at the suppressed frequencies will be equal to the current which was supplied by the unit which was shut down, or the reduction from straight six-phase operation will be four to one. This reduction is approximately realized in practice as shown by the ratios in the last column of table III. The reduction factor for the $I \cdot T$ product is about three to one.

A comparison of the data for "balanced" operation in tables II and III shows that the phase-shifting transformers are about equally effective whether applied to a station comprising three delta and two wye units, or three wye and two delta units.

Supply-System Wave Shape and Telephone-Circuit Noise

The previous comparisons have been made on the basis of the improvement effected by 30-phase operation of the rectifiers compared with straight 6-phase operation. Actually, before the installation of the phase-shifting transformers, four of the units in the first station at Alcoa made up two 12-phase rectifiers, with one extra 6-phase unit. This method of operation made substantial reductions (as compared to straight 6-phase operation) in the harmonic line currents at 300, 420, 1,020, 1,140 cycles, etc., while accomplishing no reduction at 660, 780, 1,380, 1,500 cycles, etc. The wave-shape and noise tests which indicated the necessity for further reductions in the harmonics were made with this arrangement, and under a variety of supply-system conditions presenting different system impedances as viewed from the rectifiers. To indicate the improvement in wave shape and noise conditions accomplished by the installation of the phase-shifting transformers, the summary of table IV is included. The maximum noise values on exposed telephone toll circuits are included merely to indicate the order of improvement effected on a large number of circuits when the phase shifters were installed.

Tests made at Massena following the installation of the 27,500-kw (five-unit) station equipped with phase-shifting transformers indicated that the rectifiers had practically no effect on the wave shape of the 110-kv supply system under the "balanced" operating condition, and a relatively small effect when one unit was out of service, as indicated in table V.

Final tests were made at Alcoa after the completion of the second station and with phase-shifting transformers installed ahead of all ten units to provide 60-phase operation. The results of these tests under three power conditions are shown in table VI and indicate that voltage-wave-shape conditions under balanced operation compare favorably with those existing before the rectifier station was installed. The effects of grid control and of "unbalanced" operation with one unit out of service are also shown in table VI.

Table V. Effect of 30-Phase Rectifier Operation on Voltage TIF of Supply Systems to Massena 27,500-Kw Rectifier

Circuit	Rectifiers Off	Balanced Rectifiers	One Unit (No. 3) Out of Service
Power condition (a)			
Massena rectifier 13-kv bus	12.1	28.8	69
Massena 110-kv bus	14.8	15.8	21
Location 1—13-kv bus	20.7	20.6	22.8
Location 2	27*	24*	32*
Power condition (b)			
Massena rectifier 13-kv bus	9.1	48	75
Massena 110-kv bus	14.1	14.7	15
Location 2	28.8*	32.5*	35.7*

* 1,500-cycle component from 450-horsepower synchronous motor on motor generator set controlled the voltage TIF at location 2. TIF observed with motor off, but with balanced loads on the rectifiers, was 11.

Conclusion

As demonstrated in the case of these large rectifier installations, the introduction of autotransformers as phase shifters offers a very attractive means of reducing harmonic components which otherwise would be outstanding where multiunit rectifiers are involved. In situations of

Table VI. Power-System Influence Measured With 55,000-Kw 60-Phase Rectifier Operating at Alcoa

	Voltage TIF			
	13-Kv Rectifier Bus	154-Kv Bus	120-Kv Bus	Total 13-Kv I·T Product
Power condition a-2				
Rectifiers off	10.0	9.0	10.0	
Balanced (no control)	14.3	11.0	4.5	37,000
Balanced (5 per cent control)	14.5	10.2		48,000
Unbalanced* (no control)	37.0	40.5	12.6	154,000
Power condition a-1				
Rectifiers off	10.0	9.0		
Balanced (no control)	28.2	12.8		42,000
Balanced (2 per cent control)	31.5	19.2		45,000
Unbalanced* (no control)	67.0	37.0		126,000
Power condition a-3				
Rectifiers off	10.0	14.0		
Balanced (no control)	15.2	11.9		43,500
Balanced (5 per cent control)	17.4	11.6		65,000
Unbalanced* (no control)	40.3	41.5		153,000

* One unit shut down—nine units operating.

this character, this method of improving wave-shape conditions has proved not only effective but also simpler and more economical than the application of filtering devices, usually consisting of a combination of reactors and capacitors, which have been used to some extent with satisfactory results in smaller rectifier installations.

The application of phase shifters is by no means limited to the present arrangement, but can be adapted to a variety of conditions. For instance, in case four units (with four or eight tanks), instead of five units as in the above stations, would suffice to meet the required load, a 24-phase system could be arranged by using one phase shifter, giving a relative phase displacement of 15 degrees, in connection with two rectifier groups, each consisting of a transformer with a wye and with a delta connected primary. The same result could be secured by using two identical phase shifters for plus and minus 7.5 degrees. In case three units (with three or six tanks) would take care of the required load, or if larger rectifier units could be built to meet the load of the stations described above, an arrangement could be used comprising three 12-phase rectifier units, one shifted plus 10 degrees and another minus 10 degrees, resulting in 36-phase operation. Such an arrangement would appear to offer some advantage over the present 30-phase system, as it would require only one type of rectifier transformer, although of a more complicated construction, and one design of phase-shifting transformer. The 12-phase system could be obtained with one wye and one delta 6-phase transformer as one unit, or the conventional 12-phase with quadruple secondary. This would simplify the problems of design, installation, and eventual replacement, and should result in an even better wave shape than the 30-phase arrangement. However, the flexibility of the station would be somewhat impaired due to the smaller number of units. Other arrangements may, of course, be used to suit the particular requirements of each case. When the supply-system impedance conditions are such that the influence is materially affected by those harmonic components which are unsuppressed with the particular arrangement employed, it should be relatively simple to reduce these components by means of selective devices.

The solution of the wave shape and noise problems presented by these large rectifier installations is an illustration of the results which can be achieved by cooperation between the electrical manufacturer, the purchaser of electrical equipment, the power-supply companies, and the communication companies. It is expected that the experience gained during this study will be valuable in the design and installation of future large rectifier stations.

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Discussion

F. O. Stebbins (General Electric Company, Schenectady, N. Y.): This paper presents an entirely adequate solution of this particular communication-circuit noise-level problem and because of its complete form and the factual data contained therein is a valuable contribution to the literature on this subject.

Apparently the noise level at rated kilowatt load, with all units operating (at approximately equal kilowatt load per unit) is well below the minimum acceptable values. It may be assumed that with the same kilowatt load imposed on four units instead of five or nine tanks instead of ten that the noise levels in the high-voltage bus materially affecting communication circuits were still within acceptable limits.

In studying this problem was it possible to (1) establish some minimum acceptable noise level as an objective; (2) determine whether the 13-kv or the high-voltage (110 or 154 kv) lines would govern permissible noise levels?

Due to the very nature of electrochemical operations all equipment must be capable of carrying rated load 24 hours per day, 365 days per year. Hence the determination of an acceptable minimum noise level under the least favorable operating conditions (such as normal kilowatt load imposed on four instead of five units or nine instead of ten tanks) is most important, and may have a material influence on station layouts, provisions for spare capacity, etc.

Local conditions, at the point of installation, such as (*a*) the capacity and extent of a-c power supply, (*b*) interconnection of this system with other systems, (*c*) exposure of open-wire main-trunk-line communication systems to the power supply, (*d*) the number of high-voltage transformations in the complete system have an important effect on the solution of this noise-level problem.

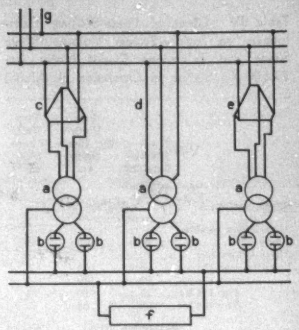


Figure 1. Large rectifier plant with 36-phase connection

a—12-phase transformers of identical construction, output 8,000 kw each
b—Two 5,000-ampere 800-volt rectifiers per transformer
c—Phase shift transformer for plus ten degrees
d—Without phase-shift transformer
e—Phase-shift transformer for minus ten degrees
f—Load
g—Supply lines

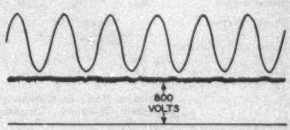


Figure 2. 36-phase connection obtained by parallel operation of three 12-phase transformers, each for 10,000 amperes, 800 volts

Common primary current of the three rectifier transformers

As examples the 60,000-kw station of the Consolidated Mining and Smelting Company at Trail, B. C., and the 54,000-kw station of the Aluminum Company of Canada do not at present require equipment to improve the wave shape of the power supply. All of these factors may be studied prior to installation and an approximate solution attained.

The harmonic reductions the authors obtained with the 30-phase group seem to approach maximum values approximately halfway between the frequencies that the 30-phase group does not suppress. That is, these reductions increase to maximum values at 13th and 43rd harmonic frequencies, but are zero at 29th, 31st, 59th and 61st harmonic frequencies, etc. Did the authors find that this same characteristic applied also to the 60-phase group, and the reductions in the harmonics approach a maximum at approximately 29th harmonic frequencies? Also how did the harmonic reductions of the 60-phase group compare with those obtained with the 30-phase group?

We note that the authors built and tested a miniature 30-phase rectifier in their fac-

tory and made a study of the effect of unbalanced 30-phase operation by shutting down one unit in a 30-phase group. The poorest wave shapes obtained with unbalanced operation, which are shown on the oscillogram taken in the factory, are made evident later in the rectifier installations at Alcoa and Massena, where unbalanced operation increased the voltage TIF on the 13-kv station bus, approximately two to one.

We would like to know whether the authors' tests showed that the large harmonic reductions obtained on the a-c side of the 30-phase rectifier also were found to exist on the d-c side of the rectifier. Did these reductions increase to maximum values at frequencies halfway between the 30th and 60th harmonic frequencies, as they did on the a-c side of the rectifier?

It has been found that odd harmonics in the a-c supply voltage wave to a rectifier come through to the d-c side of the rectifier as even harmonics of approximately the same percentage value. Did the authors learn whether a 30-phase or a 60-phase group will tend to reduce the percentage values of the harmonics in the d-c output voltage, produced by harmonics in the a-c supply voltage?

Have the authors reached any conclusions regarding the economic limit of filtering equipment, that is the maximum kilowatt rating of a station at which the filter is a more economical solution to the wave-shape problem than the phase-shifting autotransformer?

E. V. DeBlieux (General Electric Company, Pittsfield, Mass.): The authors of the paper have made a valuable contribution to rectifier operating experience in reporting the results of tests of the Massena and Alcoa installations. These tests demonstrate that wave-shape distortion of rectifier installations can be reduced to acceptable values by phase multiplication.

The required kilowatt output of the station, purchaser's specifications covering the number of operating units, and operating requirements as to spare capacity, will determine the number of units (transformer and associated rectifiers) in a given station. At the present time the units must operate either in 6-phase or 12-phase relationship to the supply system. These factors will determine what can be done by way of phase multiplication to minimize TIF. I believe that there is little advantage in going to more than 36, or possibly 48 phases, because the higher harmonics are a small item in the TIF, extreme accuracy of phase shift is required to eliminate these higher harmonics (see figure 7b of the paper), and also unless the output is very large it is not economical to divide the installation into the large number of units required.

The authors state that due to various factors, complete elimination of certain harmonics was not realized. Were any tests made to determine whether or not it would be possible to improve the harmonic elimination by unequally dividing the load or by altering the phase shift between units? Figures 1 and 2 of this discussion are a connection diagram and an oscillogram of a German installation that consisted of several 24,000-kw 36-phase sets using a connection similar to that at Alcoa. The oscillogram shows the same excellent line-current wave shape as figure 6 of the subject paper. In the German installation reactors were connected in the rectifier cathode lines to limit the harmonic currents that circulate between rectifiers and transformer secondaries as a result of the phase displacement between units. Did the authors of the paper take oscillograms of anode current or other measurements to determine the magnitude of the circulating harmonic currents in their installation?

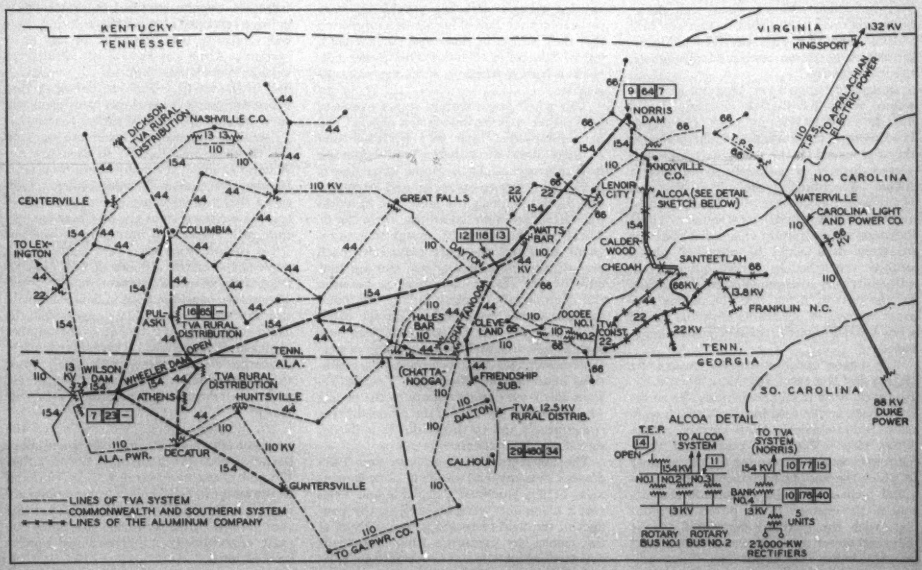
S. A. Flemister (Southern Bell Telephone and Telegraph Company, Atlanta, Ga.): The paper by Doctor Marti and Mr. Taylor contains much interesting information regarding the many important electrical features of a large mercury-arc-rectifier installation such as that at the plant of the Aluminum Company of America at Alcoa, Tenn. Of most interest and concern to telephone engineers are, of course, those features relating to the harmonics impressed by the rectifiers on the connected a-c power-supply network, since it is through the propagation of these harmonics over the connected high-voltage transmission lines and thence over the urban and rural distribution systems connected therewith that the noise-influence problem may become important.

As it was my good fortune to participate in the tests and analyses made in connection with the Alcoa installation, the paper under discussion is most interesting to me. While the paper covers rather completely

Figure 3. Voltage telephone influence factors measured at various points

27,000 kw of rectifiers supplied from TVA only

The value in the left-hand side of the box at a given location shows the voltage telephone influence factor without rectifiers on system. The value in the center of box shows the voltage TIF with rectifiers and without phase-shifting transformers. The value in the right-hand side of box shows the voltage TIF with rectifiers and with phase-shifting transformers



the technical aspects of the problem, I believe it will also be of interest to describe the scope of the problem and the co-operative arrangements which so facilitated the testing work and the ultimate solution.

To illustrate the scope of the problem from the operating standpoint, figure 3 of this discussion has been prepared to show the wide geographical area and the extensive connected transmission-line network involved. By reference to the figure, it may be seen that the area included large parts of the states of North Carolina, Georgia, Alabama, and Tennessee, which are served by a part or all of the transmission-line systems of the Carolina Power and Light Company, the Nantahala Power Company (owned by the Aluminum Company), the Tennessee Public Service Company, the Tennessee Valley Authority, the Tennessee Electric Power Company, the Alabama Power Company, and the Aluminum Company of America. As can be appreciated, in addition to the network of transmission lines shown, there were extensive connected urban and rural distribution networks, many of which were involved in inductive exposures to the circuits of the telephone plant.

Based on experience with other (smaller) rectifier installations and on the studies made by the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell Telephone System, it seemed quite probable from the beginning, that a rectifier installation of the magnitude contemplated would result in widespread and important increases in power-system influence and in the noise on telephone systems exposed to the circuits of the connected power network. In view of this, the problem was discussed at an early date with all of the power organizations whose systems might be affected as well as with the Aluminum Company and the Allis-Chalmers Company. All of these organizations were very interested and expressed their desire to do whatever they could to find the best possible solution. This wholehearted interest and co-operation continued throughout the investigation.

In deciding upon a test program and procedure, it was felt that the program should include not only tests at Alcoa, but simultaneous tests at strategic outlying points in the area served by the power networks connected directly or indirectly to the bus at Alcoa. Accordingly, single-line diagrams of the power systems involved were studied and the field-test locations selected. These locations were carefully selected so that the pertinent data could be obtained and a suitable test schedule worked out to fit in with switching arrangements, etc., necessary for the tests at Alcoa. As the testing program progressed, it became desirable to add a few field locations to those originally designated.

The paper under discussion covers the testing and test results at Alcoa quite fully. However, little is said concerning the correlated tests at the field locations which were made simultaneously with certain of the Alcoa tests. The chief purpose of these field tests was to determine by the manner in which the various harmonics were propagated from Alcoa, the magnitude and extent of the changes in the power-line influence with the rectifiers connected to the different power systems under normal and probable emergency power operating conditions. Tests at these locations were all made with instruments of the indicating type and consisted of voltage-wave analyses, noise tests on selected representative telephone circuits, and measurements of the telephone influence factor (TIF).

As an indication of the extent of propagation of the harmonic voltages arising in the rectifiers, the measured TIF values at several locations are shown in the figure for one of the power operating arrangements tested. This is the condition of the TVA system only supplying 27,000 kw of rectifiers, which represented half the station capacity. Three values of measured TIF are shown in boxes at the selected locations for the TVA system. In the box to the left is shown the reference value of TIF measured with no rectifier load connected to the power system. The value in the middle shows the measured TIF with the rectifiers connected to the system but with the phase-shifting transformers out. In the right of the box is shown the TIF value with the rectifiers supplied through the phase-shifting transformers.

The final solution adopted was, as discussed in the paper, accomplished by the provision of specially designed phase-shifting transformers. These particular transformers are, as indicated by the data shown on the figure, amazingly effective in reducing the harmonics which would otherwise be impressed on the connected power network. A satisfactory reduction might have been accomplished through other means, such as the use of filters, etc. However, had filters been employed, they probably would have been more costly and their effectiveness would have been dependent upon keeping the power-system impedance nearly the same as that assumed in the design of the filters. This restriction would, of course, have been very undesirable from the power operating viewpoint. The use of the phase-shifting transformers has provided a very satisfactory method of harmonic suppression and their action in this respect is independent of changes in the connected power network, a feature which is, of course, most desirable.

This whole investigation seems to me to be a rather striking illustration of what can be accomplished in a very complex (and at times almost discouraging) problem when it is approached by a group of engineers working in close co-operation and interested only in determining the facts and in working out a solution based on these facts. There is no need and not enough time to recount in detail the part played by each organization because any one can see that only by the closest co-ordination between the Aluminum Company on the one hand and the power organizations on the other could it be possible to carry out tests over such a wide area and under so many power-system arrangements and operating conditions smoothly and efficiently. I cannot refrain also from paying tribute to the people who conceived the idea of the phase-shifting transformers and to those who actually designed and built them.

The Southern Bell Telephone and Telegraph Company and the long-lines department of the American Telephone and Telegraph Company were assisted in the conduct of the field tests and in the analysis of the results by engineers from the headquarters organization of the American Telephone and Telegraph Company and Bell Telephone Laboratories in New York. The Western Union Telegraph Company and the Southern Railway, which operate communication facilities in the area, were kept in close touch with the study.

O. K. Marti and T. A. Taylor: Mr. Flemister's discussion supplements the data in the paper and emphasizes the scope of the co-ordination problem and the co-operative arrangements employed in its solution.

In answer to the question of Mr. DeBlieux, no tests were made to determine the effect on harmonic reduction of unequally dividing the load or altering the phase shift between units. An effort was made to keep the loads balanced and no provision was available on the phase-shifting transformer for changing the phase shift. While some improvement might be made by these changes, neither change seems practicable in commercial operation. No measurements were made of the magnitudes of the circulating harmonic currents during the joint study. However, some data were secured by the Allis-Chalmers Company and will probably be included in another paper covering additional aspects of this installation.

In answer to Mr. Stebbins' question, there is, of course, no practical method of setting up definite limits for noise or power-system influence. In this particular case the power-system influence and the noise levels on exposed telephone circuits before the rectifiers were placed in operation were taken as the primary objective in determining the desirable reductions in the harmonics. This objective was fully met under conditions of balanced operation of the station, although some increases in influence and noise were noted with unbalanced operation. Since the principal exposures were to power distribution circuits supplied from the high-voltage systems (110 and 154 kv), and there was relatively little exposure to the 13-kv system at Alcoa, the wave shape of the high-voltage system was assumed to be controlling in the study. The authors agree that many factors such as those mentioned will enter into the solution of such a problem.

Detailed measurements were not made on the 60-phase installation, so data are not at hand to make the comparison requested. However, the over-all measurements indicated that the 60-phase connection was at least as satisfactory as the 30-phase connection with respect to harmonic reductions.

No co-operative tests were made on the wave shape of the d-c end of this installation, since no noise problem was involved. Theoretical considerations indicate that substantial reductions would be expected in the harmonics on the d-c output as the number of phases is increased. This is particularly important from the standpoint of the use of the larger number of phases in connection with d-c transmission and merits further study.

No definite conclusions regarding the economic limit of filtering equipment have been reached. In general, it appears that the multiphase connection will be restricted to the larger installations, where all units are operated in parallel at constant load, while the various filter arrangements may be more economically applied to the smaller installations.

Lightning Investigation on Transmission Lines—VII

W. W. LEWIS
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THE lightning investigation reported in previous papers of this series was continued in 1937 and 1938, with the following power companies participating:

Pennsylvania Power and Light Company
Ebasco Services, Inc.
Appalachian Electric Power Company
American Gas and Electric Company
Consumers Power Company

The following companies also co-operated by furnishing pertinent information:

Pennsylvania Water and Power Company
Philadelphia Electric Company
Public Service Electric and Gas Company

Work was confined mainly to a study of magnitude and distribution of current in tower members, overhead ground wires, conductors and counterpoise wires. All readings were taken by means of magnetic links.[1] The present paper constitutes a progress report on certain features of the investigation.

Current in Towers and Strokes

In the immediately preceding paper of this series,[2] cumulative curves were shown of tower and probable stroke current, involving 358 strokes on four systems, during the years 1933, 1934, and 1935.

Figure 1 of the present paper shows similar curves for 734 strokes, on seven lines ranging from 66 to 220 kv, during the four years from 1933 to 1936 inclusive. The shapes of these curves do not differ greatly from the previous curves.

In working up the data for figure 1, tower currents were found by adding the currents in the four legs and neglecting any currents that might flow in the diagonal members or braces. Stroke currents were found by adding currents in all towers affected by the stroke. As ordinates the average of each 10,000-ampere range has been plotted.

In 1937 and 1938 a number of installations were made in which magnetic links were placed on cross members or braces in addition to the corner legs. It was found that the cross members carried from 30 to 100 per cent as much current as the legs, depending on how symmetrical the counterpoise arrangement was with respect to the tower legs. However, no currents were measured which indicated tower or stroke currents in excess of those shown on figure 1.

Occasional questions have been raised as to the validity of the method of obtaining stroke current by adding currents in adjacent towers which appeared to be affected by the same lightning discharge. Accordingly measurements obtained near the tower top and before current subdivision had taken place have been analyzed to show direct-stroke currents. These records were obtained on tower-top lightning rods and overhead ground wires and are summarized in table I.

This table includes some 80 records obtained over several years operation and on four different lines. The percentage figures from table I have been plotted on figure 2 against the average of each 10,000-ampere range. For comparison the stroke-current curve from figure 1 has been reproduced on figure 2.

The direct measurement in rods and ground wires shows a higher percentage of strokes in the low-current range and a lower percentage of strokes in the high-current range. The higher percentage of low-current strokes is not due to current sensitivity of the measurement stations because considering division of current, the rod and ground wire stations recorded down to about the same current level as the tower stations. Possibly in interpreting stroke currents by addition, some low-current records which were considered portions from another stroke should have been classified as direct strokes. The lower percentage of high-current strokes obtained through rod and ground-wire measurements results from two circumstances: A number of currents extended above the upper limit of range of the measurement station. Also, it is quite reasonable that in adding up tower currents to obtain stroke currents a few excessively high records were obtained in assigning adjacent tower currents to a single stroke when in fact more than one stroke occurred. The agreement between the different methods of evaluating the stroke current is fairly good. For practical purposes, an upper limit of current somewhere between the two curves, say 150,000 amperes, may be chosen.

Lightning Currents in Line Structures

Comparing surge currents and surge-current summations in various parts of the line structure is frequently disappointing unless attention is given to a number of possible current combinations. An analysis has been made of 42 sets of records wherein currents flowing up the tower structure could be compared with corresponding currents leaving the tower top through overhead ground wires and lightning rods.

A direct comparison of "inward" with "outward" flowing currents is possible if the tower top is considered as the summa-

Table I. Range of Direct-Stroke Currents

Range of Current (Amperes)	Lightning Rods		Overhead Ground Wires	
	Number Strokes in Range	Per Cent of Number Exceeding Current Range	Number Strokes in Range	Per Cent of Number Exceeding Current Range
Below 10,000	0	100	6	88
10,001– 20,000	4	87	4	80
20,001– 30,000	3	77	6	68
30,001– 40,000	7	53	7	54
40,001– 50,000	9	23	13	28
50,001– 60,000	3	13	4	20
60,001– 70,000	1	10	4	12
70,001– 80,000	3	0	1	10
80,001– 90,000			1	8
90,001–100,000			2	4
100,001–110,000			2	0
Total	30		50	

Paper 39–122, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939. Manuscript submitted April 18, 1939; made available for preprinting May 8, 1939; released for final publication August 23, 1939.

W. W. Lewis is in the engineering division of the central-station department and C. M. Foust is in the general engineering laboratory, General Electric Company, Schenectady, N. Y.

1. For all numbered references, see list at end of paper.

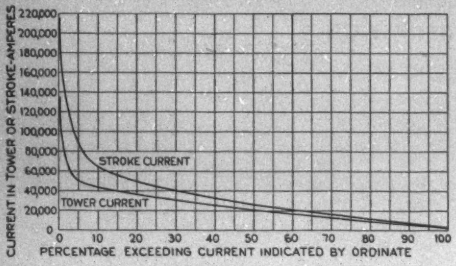

Figure 1. Cumulative curves of tower and probable stroke currents from 734 strokes occurring during the years 1933 to 1936 inclusive on the Wallenpaupack-Siegfried, Glenlyn-Roanoke, Safe Harbor-Westport-Takoma, Philadelphia-Delaware state line, Safe Harbor-Perryville, Holtwood-Coatesville and Holtwood-York transmission lines, ranging in voltage from 66 to 230 kv

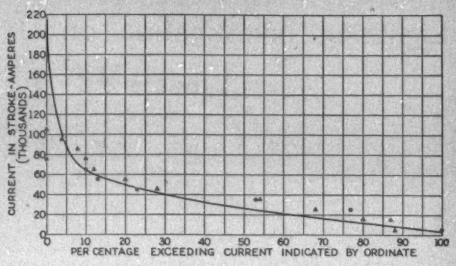

Figure 2. Stroke-current curve of figure 1 reproduced. For comparison, currents from lightning-rod measurements (circles) and overhead-ground-wire measurements (triangles) are indicated

tion point, and current polarities or current direction as indicated by the magnetic links are noted.

If currents are combined by simple algebraic addition a wide range of results is obtained. "Inward" and "outward" currents agree in about 25 per cent of the 42 cases, "inward" currents are in excess of "outward" in about 50 per cent and "outward" in excess of "inward" in about 25 per cent of all cases.

In table II are shown specimen records wherein "inward" and "outward" current values agree within plus or minus ten per cent.

In all of the cases of table II, current flowing along the ground wire or wires was joined by current flowing up the tower, and in each case current flowed into a stroke to a ground wire.

The most common case is one in which upward-flowing tower current exceeds the outward flowing current at the tower top. A number of specimens of such records is given in table III.

The first two cases are associated together because the towers are adjacent and the stroke was to a ground wire between them. Records indicate another low-current stroke to have occurred two tower spans away during the same period of exposure of these magnetic links.

For the third item where the tower-cage current was 69,630 amperes, the parallel counterpoise wire fed some 30,700 amperes into the tower base. As this counterpoise wire was connected only on one side of the tower the cross-members' currents were very high, exceeding the leg currents in magnitude. In this case, that of a two-ground-wire line, ground-wire currents flowed past the tower top in one direction on one overhead ground wire and past the tower top in the opposite direction on the other ground wire. Indications are that two strokes were present, one to the structure itself and one nearby to one of the overhead ground wires.

The fourth case is again one in which the upward current in the tower when increased by the inward flowing current in the ground wire, exceeded the outward-flowing ground-wire current. Here, however, the 70,000-ampere outward-flowing current saturated the magnetic link in the inner position leaving only the outer link available for measurement purposes. Some degree of oscillation in this current or a low magnitude reversed current would readily reduce an 82,000-ampere single-link indication to 70,000 amperes.

The fifth item, a 57,000-ampere stroke to a lightning rod, included three ground-wire currents flowing inward toward the tower top. The reading on the fourth ground wire was wiped out by a stroke to this ground wire in the adjacent tower span. However, an inward-flowing current in this wire would still further unbalance the tower-top current summation.

For the sixth item a lightning-rod stroke of 62,000 amperes gave inward-flowing currents on all four ground wires. A continuous counterpoise wire carried 37,700 amperes inward toward the tower base.

Specimen cases in which the tower-cage current when combined with inward-flowing tower-top current was less than outward tower-top current are given in table IV.

The first item of this group was a direct stroke to a tower-top lightning rod with four overhead ground wires all carrying current inward to be combined with 11,870 amperes flowing up the tower. The counterpoise wires at this tower carried a combined value of 16,470 amperes into the tower base. No other strokes reached the line nearby.

The second item pertains to a stroke to the ground wire near the tower top concerned, in which two ground wires carried current inward to the tower top and two outward. Crow-foot counterpoise wires carried inward to the tower base only 3,760 amperes as compared to 9,460 upward in the tower cage.

In the third item records were obtained when a stroke occurred to the ground wire adjacent to the tower concerned. No other strokes occurred to the line in this vicinity. In the fourth record, ground-wire currents flowed outward in both directions. Adjacent strokes occurred on each side of this tower.

These specimen records show clearly the difficulties involved in simple addition of surge-crest-ammeter records. In many instances it is possible upon careful consideration of all data to recognize difficulties in the way of good checks.

Table II. Comparison of Inward and Outward Currents at Tower Top, Showing Good Agreement

Item	Combined Leg and Brace Amperes	Ground-Wire Amperes		Combined Amperes	
		In	Out	Inward	Outward
1	11,870	8,150	18,400	20,020	18,400
2	13,350	10,200	23,000	23,550	23,000
3	15,600	2,800	17,700	18,400	17,700
4	11,250	9,160	19,800	20,410	19,800

Some of the circumstances which militate against good checks in addition of records are included in the following summary:

1. Nearby strokes causing overlapping surges.

2. High currents in nearby structure members other than the one to which the measurement station is attached.

3. Insufficient magnetic-link records to measure crest currents when oscillations or reversed currents are present.

4. Crest-current values in the several members under consideration not being simultaneous.

The fourth of these items is concerned with the nature of the distribution of cloud and ground charge. That the complete charge participating in a stroke is spread over a considerable area is commonly accepted. Also, such oscillograms of lightning-current wave shapes as have been recorded have shown complex wave shapes. Repetitive strokes are now generally recognized and it is presumed by many that each discharge taps a somewhat different cloud charge position. Continuing from these considerations it is reasonable that the several currents in different overhead ground wire and structure members will not all reach crest at the same time, which of course is the assumption on which addition of member currents is based.

Overhead-Ground-Wire Current

In view of the difficulties involved in the problem of summation of currents in line structures it is very desirable to have field records for examination, from which a reasonable criterion of comparison of measurements from station to station can be made. Fortunately, in many cases the two stations at each end of the ground wire within the tower span are carrying the same current if no stroke occurs within the span.

Some 230 records of this type in which the sending and receiving ends were carrying the same current have been accumulated during the last three years. These records ranged from 1,000 to 28,000 amperes and are of three kinds: first, records in which two magnetic links recorded intensities within the link magnetization range; second, records in which currents were low and only the inner magnetic link recorded; and third, those cases of high currents in which the inner link was magnetically saturated and only the outer-link record was available for current interpretation. All 230 records have been summarized in table V.

In this table the average of each pair of sending and receiving end stations is accepted as a reference and the percentage of deviation of the actual recorded current from it taken. In column 2 are given the number of individual records within each per cent deviation and in column three the percentage of the total records in each deviation range.

The magnetic links are selected to record crest surge currents within an accuracy of plus or minus ten per cent. On this basis some 70 per cent of the sending and receiving end stations checked each other accurately. Several of the known circumstances working against a check and quite likely responsible for the deviations greater than plus or minus 10 per cent, are as follows:

1. In a great number of cases one station will provide two link readings from which oscillatory calibrations can be used, while the corresponding station at the adjacent tower will provide only a single link reading subject to the unidirectional calibration. If some degree of oscillation is present the two-link station will indicate a higher crest current. This circumstance accounts for the greater number of excessive differences particularly of the higher percentages.

2. Possible streamer and stroke disturbances occurring between the two stations.

3. Cases where link magnetization is disturbed prior to calibration.

Table III. Comparison of Inward and Outward Currents at Tower Top, Inward Greater Than Outward

Item	Combined Leg and Brace Amperes	Lightning-Rod Amperes	Ground-Wire Amperes		Combined Amperes	
			In	Out	Inward	Outward
1	24,820		22,100	32,500	46,900	22,100
2	21,290		21,650	32,180	42,940	32,180
3	69,630		20,350	70,000	89,980	70,000
4	58,650		23,500	70,000+	82,150	70,000+
5	42,080	57,000	40,960	None	83,040	57,000
6	58,460	62,000	26,130	None	84,590	62,000

Table IV. Comparison of Inward and Outward Currents in Tower Top, Outward Greater Than Inward

Item	Combined Leg and Brace Amperes	Lightning-Rod Amperes	Ground-Wire Amperes		Combined Amperes	
			In	Out	Inward	Outward
1	11,870	33,000	8,820	None	20,690	33,000
2	9,460	None	5,200	23,500	14,660	23,500
3	15,900	None	3,800	28,500	19,700	28,500
4	14,250	None	None	32,200	14,250	32,200

Polarities of Strokes to Transmission Lines

Lightning strokes to transmission lines are predominantly negative in polarity, that is, current flows from positive earth

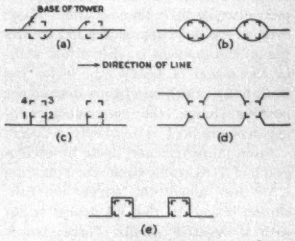

Figure 3. Typical arrangements of tower-to-tower counterpoise wires

to negative cloud. In figure 1 are summarized a total of 734 strokes accumulated from 1933 to 1936 inclusive. Of these, 685 or 93 per cent were negative and 49 or 7 per cent were positive. This total undoubtedly omits many strokes below 5,000 amperes and omits all below 2,000 amperes. That a considerable number of such low-current strokes do occur, at least under the conditions of projections of considerable height above the earth, has been definitely determined.[3] The indication is that these low-current strokes are generally of the continuing type and associated with upward-stepped leaders.

As regards cloud polarities a very interesting study has recently been reported[4] in which in addition to ground-surface gradients, soundings were made at various elevations up through the cloud by small free balloons. The results of this investigation suggest that "the main body of a thundercloud is negatively charged and that the upper part is generally charged positively." Also that "there is good evidence of the frequent occurrence of a local concentration of positive charge in the base of the cloud

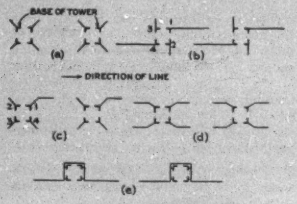

Figure 4. Typical arrangements of radial or noncontinuous counterpoise wires

usually just in front of the heavy rain center, but sometimes in other parts of the base."

Regarding the field at the ground, after combining records of some 20 storms, the authors[4] conclude that under the main body of a thundercloud the gradient is more often negative than positive. However, as the cloud approaches and recedes the ground gradient is positive and within the region of heavy rain under the main body, which rain brings down a net positive charge, the preponderance of negative gradient is markedly reduced.

From measurements[3] made by oscillograph of 55 lightning strokes to a building 1,250 feet above the street, the conclusion is reached that all strokes began with a negative cloud. Three strokes changed to positive at or near the end of the stroke and only three per cent of the total charge measured was associated with the positive portion of the strokes. In one case a continuing low current of only several hundred amperes was followed later by a negative discharge having a crest of 1,500 amperes, which was followed by a positive discharge of 2,000 amperes. These data show that mixed polarities are occasionally present in a single lightning stroke. Such a mixed polarity stroke or a sequence of mixed polarity strokes, when measured with magnetic links, will indicate an oscillatory surge and many such records have been obtained.

All magnetic-link records indicating oscillatory polarities have been interpreted through the use of an oscillatory calibration chart,[5] which was obtained in the laboratory using oscillatory calibrating surges of constant logarithmic decrement. It is obvious, therefore, that where mixed polarity surges are present and especially when the positive and negative magnitudes are of the same order, the interpretation will be correct only when the wave shape is that of a damped oscillatory capacitor discharge of constant logarithmic decrement. However, the use of such a calibration will invariably, it is believed, permit a closer approximation of the true current than would be obtained from the unidirectional polarity calibrations.

Counterpoise Wires

Counterpoise wires are in use on various systems ranging from 66 kv to 287 kv. The material used is stranded copper conductor, stranded steel conductor, stranded copperweld conductor, stranded iron wire, flat steel strip, and copper rod. The stranded copper was 1/0 and 2/0, the galvanized steel and copperweld varied from $^2/_8$ inch to $^5/_8$ inch in diameter, the copper rod was $^1/_4$ inch in diameter and the steel strip $^1/_{16}$ by 1.5 to 2 inches.

There is insufficient data to say that any of these materials or sizes is better than any other. Length of life and freedom from theft has played a large part in the choice of material.

One of the main objects of our investigation was to learn how the counterpoise functions and if possible the best arrangement of counterpoise wires. Natural lightning is very intermittent and erratic, so that an investigation of this sort is bound to progress very slowly.

Figure 3 illustrates some of the arrangements of continuous (parallel) counterpoise wires that are in use, and figure 4 shows some of the radial or discontinuous arrangements.

Distribution of Current Between Continuous Counterpoise Wires and Tower Footings

With an arrangement such as shown in figure 3*c*, readings of current in tower legs 1 and 2 (including diagonals) and in counterpoise wires were recorded in 22 cases at nine towers, and by subtraction the tower-footing current was evaluated. The summation of the readings gave distribution of current as follows:

Tower legs 1 and 2	100 per cent
Continuous counterpoise	69 per cent
Footings, legs 1 and 2	31 per cent

In five occurrences at four towers readings were obtained of current in the counterpoise wire and in all four legs of the tower, figure 3*c*, and by subtraction the footing current was obtained. The average distribution of current was approximately as follows:

Tower legs (four legs)	100 per cent
Continuous counterpoise	58 per cent
Footings (four legs)	42 per cent

With an average tower-footing resistance as measured by a Megger ground tester of 69 ohms, this would indicate an apparent counterpoise resistance of about 50 ohms.

Distribution of Current Between Radial Counterpoise Wires and Tower Footings

In an arrangement such as shown in figure 4*a*, in which each limb of the counterpoise system is 50 feet long, readings on one occasion were taken in all four tower legs and counterpoise wires, and by subtraction the footing current was found. The division of current was as follows:

Tower legs (four legs)	100 per cent
Radial counterpoise wires (four legs)	42 per cent
Footings (four legs)	58 per cent

The tower had a resistance of 47 ohms by Megger ground tester, which indicates an apparent resistance of approximately 65 ohms for the radial counterpoise system.

Table V. Ground-Wire Sending and Receiving End Comparisons

Per Cent Deviation From Average of Sending and Receiving Stations	Number of Records Within the Per Cent Deviation of Column 1	Number of Records in Per Cent Within the Per Cent Deviation in Column 1
0	41	17.7
0 to 5	80	35.0
5.1 to 10	40	17.4
10.1 to 15	23	10.0
15.1 to 20	11	4.9
20.1 to 25	8	3.5
25.1 to 30	7	3.1
30.1 to 35	4	1.7
35.1 to 40	6	2.6
40.1 to 45	4	1.7
45.1 to 50	2	0.8
50.1 to 55	1	0.4
55.1 to 60	1	0.4
60.1 to 65	1	0.4
65.1 to 70	1	0.4
Totals	230	100

In an arrangement such as shown on figure 4*c*, in which the one long wire was 250 feet long and the three short wires 50 feet long, on two occasions at the same tower readings were taken of current in the four legs and in the four counterpoise wires and the footing current was found by subtraction. The average distribution of current was as follows:

Tower legs (four legs)	100 per cent
Radial counterpoise wires (four legs)	70 per cent
Footings (four legs)	30 per cent

The tower-footing resistance by Megger ground tester was 91 ohms, giving an indicated resistance for the radial counterpoise system of 39 ohms. Of the current carried by the counterpoise wires,

the 250-foot wire with 62½ per cent of the total length carried 68 per cent of the total counterpoise current.

In an arrangement such as shown in figure 4*c* readings were taken in the long counterpoise (250-foot) wire only and in the connecting tower leg number 1, in five cases at four towers, and by subtraction the footing current was found. The distribution was as follows:

Tower leg 1	100 per cent
250-foot radial counterpoise only	72 per cent
Footings (leg 1)	28 per cent

In 16 cases involving 12 towers readings were taken simultaneously in one long (150-foot) counterpoise wire and the corresponding tower leg 4 and in one short (40-foot) counterpoise and the corresponding leg 3 (figure 4*b*). By subtraction the footing current was found. The division of current was:

Tower legs 3 and 4	100 per cent
Radial counterpoise wires (legs 3 and 4)	78 per cent
Footings (legs 3 and 4)	22 per cent

The average footing resistance of the 12 towers was 129 ohms by Megger ground tester, and assuming legs 1 and 2 and connected counterpoise wires to have the same amount and distribution of current as legs 3 and 4, an apparent resistance of 36 ohms for the radial counterpoise system would be indicated. The calculated resistance of the radial counterpoise system from actual measurement by Megger ground tester of the individual wires when separated from the towers was approximately 50 ohms.

Distribution of Current Between Tower Footings and Combination of Continuous and Discontinuous Counterpoise Wires

A section of line is equipped with one parallel counterpoise wire, which is continuous if the distance between towers is 1,000 feet or less (figure 3*e*), and broken at 500 feet from the tower if the distance between towers is greater than 1,000 feet (figure 4*e*). In three cases involving three towers in this section readings were taken simultaneously in the tower legs, tower footings, and continuous or broken counterpoise arrangement. In all three cases the wire was continuous on one side of the tower and broken on the other. Following was the division of current:

Tower current	100 per cent
Continuous counterpoise	33 per cent
Broken counterpoise	27 per cent
Tower footings	40 per cent

The tower-footing resistance by Megger ground tester averaged 135 ohms, which would indicate an average apparent resistance of 164 ohms for the continuous counterpoise and 200 ohms for the broken counterpoise. The average actual resistance measured by Megger ground tester of the continuous counterpoise wires when disconnected from the towers was 65 ohms and of the broken counterpoise wires 74 ohms.

Experimental Combinations of Continuous and Radial Counterpoise Wires and Driven Rods

An experimental installation of continuous (parallel) counterpoise wires, combined with two radial counterpoise wires extending at right angles, one in each direction (figure 5*a*), was made in a sandy high-resistance territory. The continuous counterpoise wire was connected to one corner of a three-legged tower and the radial wires to the other two legs. The length between towers was about 500 feet, so that it might be considered that 250 feet of continuous counterpoise was associated with each tower in each of two directions. Each right-angle radial counterpoise was 250 feet long, or 500 feet total per tower.

In 1937 there was a stroke to the overhead ground wire between two towers. By means of magnetic links on the counterpoise wires and the tower legs, the current was evaluated and the pickup was found to be approximately as follows (the tower footing pickup being found by subtraction):

Total current	100 per cent
Continuous counterpoise pickup	38 per cent
Right-angle counterpoise pickup	43 per cent
Footing pickup	19 per cent

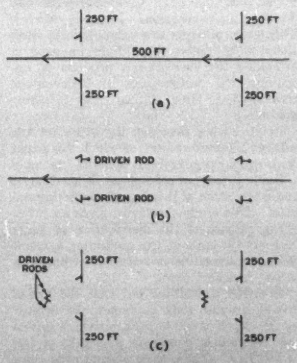

Figure 5. Experimental installations of tower-to-tower right-angle counterpoise wires and driven rods

Another experimental installation consisted of a continuous counterpoise connected to one corner of a three-cornered tower, supplemented by one or two deep-driven rods connected to the other corners, figure 5*b*, and still a third installation consisted of right-angle counterpoise wires 250 feet long extending from two corners of the tower and one or two deep-driven rods from the third corner, figure 5*c*.

In 1938 a stroke occurred to the overhead ground wire between two towers, to the left of which was the arrangement of counterpoises shown in figure 5*b* and to the right the arrangement shown in figure 5 *c*. Current was measured in the counterpoise, tower legs, and driven rods and found by subtraction in the tower footings. The distribution of current between the sections arranged as in figure 5*b* and figure 5*c* was as follows:

Total stroke current	100 per cent
Pickup in section 5*b*	74 per cent
Pickup in section 5*c*	22 per cent
Pickup in footings in both sections	4 per cent

Four towers were involved in the section arranged as in figure 5*b*. The footing resistance of these towers varied from 540 to 1,400 ohms, with an average of 831 ohms. The combined resistance of the footings and the driven rods varied from 9 to 23 ohms, with an average of 13 ohms. The apparent counterpoise resistance calculated from the distribution of current was about 61 ohms. The distribution of current between the counterpoise, driven rods, and footings was approximately as follows:

Total current picked up in section 5*b*	100 per cent
Picked up by driven rods	81 per cent
Picked up by continuous counterpoise	18 per cent
Picked up by footings	1 per cent

Three towers were involved in the section arranged as in figure 5*c*. The footing resistance of these towers varied from 665 to 910 ohms, with an average of 808 ohms. The combined resistance of the footings and the driven rods was about 13 ohms for all towers. The apparent right-angle-counterpoise resistance calculated from the distribution of current was about 46 ohms. The distribution of current between the right-angle counterpoise, driven rods, and footings was approximately as follows:

Total current picked up in section 5*c*	100 per cent
Picked up by driven rods	77 per cent
Picked up by right-angle counterpoise	22 per cent
Picked up by footings	1 per cent

It is probable that the driven rods penetrated through the sand to underlying clay or loam, while the counterpoise wires were buried in sand at very high resistance. The counterpoise wires in this experiment were equally effective whether continuous and parallel to the line or at right angles to the line. It is also apparent that in this particular territory, the deep-driven rods are more effective than the counterpoise wire.

Conclusions

1. The frequency of occurrence of lightning strokes of various current amplitudes is about the same whether measurements are obtained directly in lightning rods and overhead ground wires or amplitude values are obtained by addition of tower member and adjacent tower currents.

2. The average lightning stroke current is about 30,000 amperes. The upper level of strokes is about 150,000 amperes and possibly less than one per cent of all strokes reach this value. Stroke currents as measured range down to 2,000 amperes. Other observers using oscillographic means report strokes as low as several hundred amperes crest.[4] Some 93 per cent of all lightning strokes reaching transmission lines are of negative polarity, that is, the cloud is negative and the ground positive.

3. A summation of currents at the tower top, considered as a center for tower, overhead-ground-wire, and lightning-rod currents, shows inward and outward flowing currents equal in 25 per cent of all cases. In 50 per cent of the cases inward flowing currents are larger than outward, and in the remaining 25 per cent outward currents are larger than inward currents.

4. Seventy per cent of all records of currents flowing in overhead ground wires at adjacent stations at the ends of the same span show the sending and receiving ends to agree within plus or minus ten per cent.

5. All arrangements of counterpoise wires that have been tried have given improvement in the flashover performance of the lines, some arrangements more than others. The counterpoise wire reduces the resistance at the tower footing, reduces the earth potentials, and holds down the tower potential, thereby preventing insulator flashover.[3]

6. The data show that counterpoises of various arrangements pick up from 40 to 80 per cent of the current, as compared with the tower footings which pick up from 60 to 20 per cent. This relative amount of pickup depends on the length and arrangement of the counterpoise wires, the tower-footing resistance, and possibly other factors.

7. Counterpoise resistance calculated from the division of current between counterpoise and tower footing, agrees with the resistance measured by Megger ground tester and current divides substantially in accordance with the resistance. An exception is that of the continuous and long discontinuous or broken counterpoises, which have a low measured resistance but an actual apparent resistance to lightning current much higher and of the same order as the usual radial counterpoise. This indicates that the entire length of the continuous counterpoise is not effective in reducing the resistance at the foot of the tower.

8. In territory in which a considerable depth of sand lies on the surface, producing a very high resistance condition, driven rods offer a very effective means of reducing the tower resistance. Tests in which driven rods were compared with the continuous and right-angle counterpoises of about equal effective length, showed about 80 per cent of the current picked up by the driven rods and 20 per cent by the counterpoise wires lying in the high-resistance sand.

9. Magnetic links have proved to be very valuable in obtaining the data on current necessary for the analysis of the counterpoise problem.

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Discussion

F. W. Hartzell (The Commonwealth and Southern Corporation, Jackson, Mich.): This paper presents in a valuable form additional information that might be used in attacking the ever-present problem of improving the performance of high-voltage transmission lines during the lightning seasons.

In reviewing previous literature on the subject of counterpoises, of which this paper deals quite extensively, it is found that only a limited amount of actual field data is available, some of it being of conflicting nature. This study, however, gives an interesting picture of the distribution of surge currents throughout the grounding systems of transmission line towers as determined by actual measurements.

It might be pointed out that the use of driven ground rods is sometimes limited by the depth of soil to rock, although driven rods frequently penetrate to depths of 100 to 150 feet. These deep ground rods compare in length to some of the counterpoises that have been under investigation, so some interesting light might be thrown on the subject if these ground rods were treated as vertical counterpoises as compared to the parallel and radial counterpoises described in this paper.

It also becomes evident that individual towers, or groups of towers, should be considered separately according to ground characteristics when prescribing lightning-resistant features to any transmission line. A careful survey of the conditions to be encountered along a transmission line is therefore imperative before recommendations are made for lightning protection.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): It is not enough to discover the maximum current in lightning strokes, it is also necessary to determine how often currents of any given magnitude may occur, and Lewis and Foust have established curves, as given in figure 1 of the paper, which for several years back have been used in determining the probability of strokes of any given magnitude. These data have been of much value in helping to determine just how far one is justified in proceeding in an effort to protect against direct strokes. These data could be of still more value if the authors could give some data with reference to the number of strokes per mile of line per year which they have experienced. Information is needed with respect to stroke severity in different localities, but this is also a statistical problem which requires much time to secure a satisfactory answer.

In connection with the discussion of polarities of strokes, I would like to point out that, in reference 3 of the paper, I presented data showing that the continuing type of stroke occurred not only to the Empire State Building but was found in many strokes to substantially flat terrain. However, the evidence, thus far available, indicates that upward-stepped leaders occur from structures several hundred feet in height, and occur in a smaller percentage of the strokes as the structure height becomes lower. Thus far, I have no evidence that upward leader strokes occur to transmission lines of the usual height. Continuing strokes with downward initial leaders are common, and undoubtedly occur to transmission and distribution circuits. The continuing stroke is like a d-c arc between cloud and ground with superimposed current peaks. The arc current is often quite small, but may have a magnitude of several hundred amperes with a duration of a fractional part of a second.

It is of importance to recall that direct strokes from negative clouds release a positive bound charge on conductors in the cloud field, which may be of importance on low-voltage circuits when the rate of field change is sufficiently rapid. Only the current peaks will have such an effect, so that in an oscillogram of induced current in such a conductor the continuing part would be absent.

Although the magnetic links frequently show reversal of polarity of current in the inducing conductor, yet there is no evidence that lightning oscillates. It may change polarity, and the available data indicate that it does reverse. However, there is no apparent relation between the magnitude of the initial current and the subsequent reversal. This seems quite reasonable, if the cloud is considered as made up of groups of

Table I. Lightning-Current Measurements, 1938 Data

Area Is for Section in Which Magnetic Links Are Installed

Item No.	Test No.	Tower No.	Main Members			Lesser Members			Totals			Ratios—Total to Main		
			I_m	A_m	D_m	I_l	A_l	D_l	I_t	A_t	D_t	R_i	R_a	R_d
1	1	503	10,400	20.24	514	8,900	6.90	1,290	19,300	27.14	713	1.85	1.34	1.39
2	1	538	37,000	12.16	3,062	49,100	9.30	5,280	86,100	21.46	4,000	2.33	1.76	1.30
3	1	539	40,100	16.72	2,400	66,900	8.94	7,480	107,000	25.66	4,175	2.67	1.53	1.74
*4	1	550	10,000	23.00	436	2,000	7.12	281	12,000	30.12	398	1.20	1.31	0.91
5	1	626	27,500	23.00	1,195	14,500	7.12	2,040	42,000	30.12	1,395	1.53	1.31	1.16
*6	2	540	6,800	16.72	407	0	9.30	0	6,800	26.02	261	1.00	1.56	0.64
7	2	551	15,500	36.44	425	17,800	8.42	2,120	33,300	44.86	955	2.15	1.23	2.25
8	2	625	54,200	16.72	3,240	88,500	9.30	9,500	142,700	26.02	5,490	2.64	1.56	1.69
*9	2	626	9,000	23.00	391	0	7.12	0	9,000	30.12	298	1.00	1.31	0.76
10	3	503	9,600	20.24	474	7,800	6.90	1,130	17,400	27.14	642	1.82	1.34	1.35
*11	3	504	7,700	12.16	633	3,800	6.90	550	11,500	19.06	604	1.50	1.57	0.95
12	3	541	30,000	25.30	1,185	20,100	12.34	1,630	50,100	37.64	1,330	1.67	1.49	1.12
13	3	542	23,900	12.16	1,965	18,000	9.30	1,935	41,900	21.46	1,953	1.75	1.76	1.00
14	3	543	32,300	23.00	1,400	27,300	7.12	3,830	59,600	30.12	1,980	1.85	1.31	1.41
15	3	544	27,300	16.72	1,633	23,100	9.30	2,480	50,400	26.02	1,935	1.85	1.56	1.18
16	3	549	26,400	16.72	1,472	18,900	9.30	2,030	45,300	26.02	1,740	1.72	1.56	1.18
17	3	552	37,100	16.72	2,220	31,800	9.30	3,410	68,900	26.02	2,650	1.85	1.56	1.19
18	3	622	21,600	23.00	940	13,400	7.12	1,885	35,000	30.12	1,163	1.62	1.31	1.24
*19	3	623	3,200	16.72	185	0	9.30	0	3,200	26.02	123	1.00	1.56	0.66
*20	3	624	7,700	16.72	451	1,200	9.30	129	8,900	26.02	342	1.15	1.56	0.76
*21	3	627	4,600	12.16	379	0	8.94	0	4,600	21.10	218	1.00	1.73	0.57
22	4	540	12,200	16.72	733	10,000	9.30	1,075	22,200	26.02	855	1.82	1.56	1.17
23	4	549	29,200	16.72	1,745	16,900	9.30	1,815	46,100	26.02	1,770	1.58	1.56	1.02
24	4	550	30,400	23.00	1,320	18,700	7.12	2,630	49,100	30.12	1,630	1.62	1.31	1.23

* Due to low value of lightning current it is probable that more current than is recorded was present in lesser members. Such being the case, the true ratios would be nearer other ratios recorded.

I_m, I_l—Total current in amperes in main and lesser members, respectively

D_m, D_l—Current density in amperes in main and lesser members, respectively

I_t—Total current in amperes—all members

A_t—Total cross section in square inches—all members

D_t—Current density in amperes—all members

R_i—Ratio: total current to current in main members

R_a—Ratio: total cross section to cross section in main members

R_d—Ratio: total current density to current density in main members

A_m, A_l—Total cross section in square inches in main and lesser members, respectively

charged insulated water drops which may group themselves in unpredictable configurations, both as to size of the group and location. In the laboratory, the discharge across 30 feet of air may oscillate if the series resistance is low enough, but in nature the cloud is not a conductor, and the availability of charge at any given point of discharge is not great, and thus time factors are introduced which are not normally present in the laboratory generator. Since calibration of the magnetic-link installation had to be made in some systematic manner, the use of the laboratory oscillatory wave was the best compromise.

It is indeed fortunate that the measurement of stroke current in the lightning rod at the top of the tower so often checked the summation of currents in the tower legs, since these data have been so widely used. In view of conclusion 2 of the paper, do the authors now feel it desirable to revise slightly downward the curve of figure 1?

R. M. Schahfer (nonmember) and **W. H. Knutz** (both of Northern Indiana Public Service Company, Hammond): The recent report of Messrs. Lewis and Foust provides additional data needed in studying and applying protective measures against lightning. However, by neglecting the current carried by the lesser tower members or by assuming any fixed ratio of this current to the current carried by the main tower members, it is entirely possible that the conclusion as to the total structure current may be in error.

With the foregoing thought in mind, we installed magnetic links on 29 132,000-volt double-circuit steel towers. These installations were made just before the 1938 lightning season. The magnetic links are installed about 15 feet above the ground on all tower members which provide a lightning current path to ground. From 14 to 18 brackets and 28 to 36 magnetic links are used per tower.

During the 1938 lightning season 24 towers provided lightning-current readings. Current values, steel-member areas, current densities, together with pertinent ratios are shown in table I of this discussion.

Summaries of current and current-density ratios taken from the table are:

	Total Current to Current in Main Members	Total Current Density to Current Density in Main Members
Average	1.67	1.16
Maximum	2.67	2.25
Minimum	1.00	0.57

Eliminating the probable low values designated by an asterisk(*) these ratios are:

	Total Current to Current in Main Members	Total Current Density to Current Density in Main Members
Average	1.90	1.33
Maximum	2.67	2.25
Minimum	1.53	1.00

From the above figures, the conclusion would be drawn that the ratio of total tower current to current in the main members has a variable ratio which is greater than heretofore suspected, and that the total structure current may therefore be in excess of values previously obtained by applying a general factor to the current of the main members.

Our total tower current values will, if plotted as a cumulative graph, form a curve somewhat above curves shown by Messrs. Lewis and Foust in figure 1.

The lightning investigation work from which these data were obtained is being continued in 1939.

W. W. Lewis and **C. M. Foust**: Doctor McEachron suggests that the authors give some data with reference to the number of strokes per mile of line per year. The authors have such data on the same lines covered by the curves of figure 1, and for the same years. The figures vary widely on account of actual differences in the number of storms and strokes and perhaps partly for the reason that some lines are well covered with magnets throughout their length, thus giving a fair average per mile, while other lines have magnets only for short lengths, probably selected for the known exposure to lightning. Naturally, the strokes per mile are high at these latter classes of installation. For one line, completely equipped with magnetic links, the strokes per mile varied from 0.22 to 0.87 for different years. On another line, only six per cent of its length equipped with links, the strokes per mile varied from 15.4 to 39.2. The data for the other lines fell in between these extremes.

Doctor McEachron asks in view of con-

Arc-Furnace Loads on Long Transmission Lines

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MEMBER AIEE

LARGE electric arc furnaces are loads which frequently introduce special technical problems when served from a central-station system. The fluctuations in the load taken by the furnaces are violent, and this characteristic combined with the inherently low power factor of this type of load results in a serious flicker problem. The low power factor also may require power-factor correction, in order to maintain a reasonable voltage level and reduce transmission losses. A further complication is that the arc is an excellent source of higher-harmonic currents and voltages. Where the load or the supply lines are close to telephone circuits, this may necessitate special measures to prevent telephone interference.

Long transmission lines accentuate the problem mentioned. The longer the line, the greater will be the extent of the voltage flicker suffered by other customers on the same transmission system. On a system which operates near its stability limit, the fluctuations in line load caused by the furnaces may result in a lower allowable loading of the system. In extreme cases, load fluctuations may be timed in such a manner as to cause instability, even though the initial loading is well below the normal stability limit of the system.

Large furnace loads on transmission lines are not common. However, this type of load is increasing in importance and means should be found to handle these loads at a reasonable cost. This paper describes the solution of one particularly difficult problem, the details of which should be of value to other companies when considering the supply to proposed intermittent loads.

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Nature of Load

The Northwestern Steel and Wire Company at Sterling, Ill., has a wire mill and small steel mill, which are equipped with the usual complement of lighting and power load. Within the past few years, two three-phase electric arc furnaces with a nominal rating of 7,500 kva each have been installed as a source of steel supply. These furnaces melt a wide variety of scrap iron and steel. The furnaces are first charged with cold metal, and when this initial charge is melted, additional cold scrap is added before the metal is poured. Both the initial charge and the back-charging result in violent load changes. Figure 1 shows a photograph of one of these furnaces in use.

Supply System

The load at Sterling is supplied through a bank of 20,000-kva transformers, 132/13.8-kv, which are connected to a 132-kv line from Dixon, Ill. As shown on the diagram, figure 2, the location of Dixon is almost at the center of a 220-mile single-circuit transmission system, connecting the Powerton and Waukegan generating stations. There are two other independent 132-kv transmission circuits from Powerton to Chicago, each of which operates on a single generating unit at Powerton.

Connected to the distribution system fed from Dixon are several hydroelectric generators. However, the average running capacity of all these generators is less than 4,000 kw. There is also a steam generating station at Dixon, but this station is normally operated only for a short time during the peak period of the year. Therefore, practically the entire load distributed from Dixon is dependent upon the 132-kv transmission system for its supply. The Dixon distribution system serves most of the territory of the Illinois Northern Utilities Company, in an area of several thousand square miles.

Figure 1. Pouring metal from a 7,500-kva electric arc furnace

Load Characteristics

The Northwestern Steel and Wire Company load has a half-hour integrated maximum demand of about 17,000 kw at about 85 per cent power factor. The indicated demands occasionally exceed 25,000 kw, or 30,000 kva, most of this demand being the load of the two electric furnaces. The demand of the general power load is about 3,000 kw, not including the wire mill. The lighting load of 75 kw, served at 13,800 volts, was connected to the city distribution system which is supplied from the Dixon 33-kv bus. This was because the voltage fluctuations caused by the electric furnaces were too great for the operation of mercury-vapor lamps.

clusion 2 of the paper if the authors feel it desirable to revise slightly downward the curve of figure 1 for stroke currents. The curve of figure 1 is the result of 734 strokes and was obtained by adding current in all towers affected by a stroke. Some question has been raised as to the validity of this method. The circles and triangles of figure 2 are based on only 80 strokes, but the data were obtained in each case close to the stroke. In the case of the lightning rods, the data involved only one reading for each stroke and in the case of the ground wires involved the addition of two readings. For this reason the authors proposed a compromise upper limit of 150,000 amperes, subject to revision on the accumulation of further data.

Messrs. Schahfer and Knutz present some valuable data as to the distribution of current in the main and lesser members of the tower structure. The average ratio of total current to current in main members of approximately 1.7 to 1.9 agrees with ratios found on other systems. As indicated in the paper this ratio depends to some extent on the symmetry of the counterpoise arrangement with respect to the tower legs, as well as on the actual ratios of cross sections of lesser and main members.

The sudden changes in arc resistance and the frequent short-circuits between electrodes during the process of melting down scrap, result in a violently fluctuating characteristic for the furnace load. The extent of these load fluctuations can best be illustrated by reference to figure 3, a chart from the graphic wattmeter connected to the steel and wire company total load. The section of the chart is a typical example of the period from the initial charging to the pouring of the arc furnaces. As indicated on the chart, the load may frequently go from zero to over 20,000 kw within a period of one to five minutes, or drop off at the same rate. In spite of the violent fluctuations, the average load throughout a 24-hour period is about 60 per cent of the half-hour integrated maximum demand.

Even a close inspection of graphic meter charts does not tell a complete story on the nature of load fluctuations. The load, which apparently swings quickly from zero to 20,000 kw, does not actually make this change in one step, but rather increases by a series of steps. The maximum instantaneous step was determined by oscillograms and found to be about 10,000 kva. These instantaneous changes take place within a period of a hundredth to a tenth of a second. Figure 5 shows one such load swing with a maximum change of 7,000-kva in one cycle. These random fluctuations may come as frequently as six to ten times per second, and are very disturbing to lighting service.

Methods of Voltage Control

Voltage control was first attempted by means of automatic tap changers on the 20,000-kva transformer bank supplying the 13.8-kv bus. The adoption of this scheme was based on an estimated maximum load of 10,000 kw and on incomplete information about the arc-furnace characteristics. The tap changer was partially successful in following the slower load fluctuations of the type indicated on the wattmeter chart. In this service the tap-changer mechanism was subjected to as many as 900 operations per day.

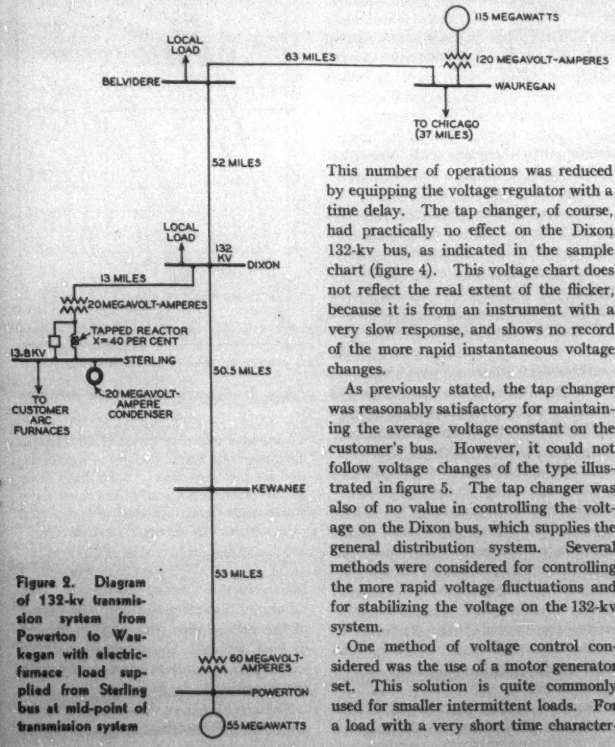

Figure 2. Diagram of 132-kv transmission system from Powerton to Waukegan with electric-furnace load supplied from Sterling bus at mid-point of transmission system

This number of operations was reduced by equipping the voltage regulator with a time delay. The tap changer, of course, had practically no effect on the Dixon 132-kv bus, as indicated in the sample chart (figure 4). This voltage chart does not reflect the real extent of the flicker, because it is from an instrument with a very slow response, and shows no record of the more rapid instantaneous voltage changes.

As previously stated, the tap changer was reasonably satisfactory for maintaining the average voltage constant on the customer's bus. However, it could not follow voltage changes of the type illustrated in figure 5. The tap changer was also of no value in controlling the voltage on the Dixon bus, which supplies the general distribution system. Several methods were considered for controlling the more rapid voltage fluctuations and for stabilizing the voltage on the 132-kv system.

One method of voltage control considered was the use of a motor generator set. This solution is quite commonly used for smaller intermittent loads. For a load with a very short time characteristic, such as a welding machine, a motor generator equipped with a flywheel and using an induction motor is very satisfactory, as the flywheel can smooth out the sudden demands. For a furnace with

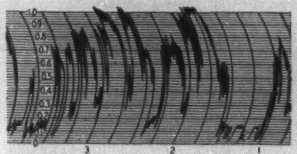

Figure 3. Arc-furnace load curve

Typical kilowatt load cycle of Northwestern Steel and Wire Company load from charging of furnaces to pouring. Full scale = 20,000 kw

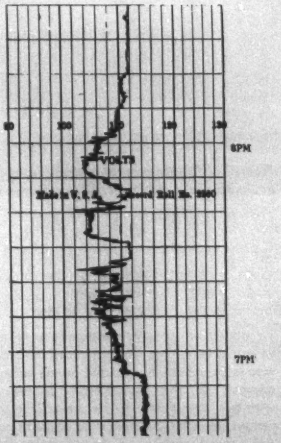

Figure 4. Effect of furnace load on Dixon 132-kv bus voltage—condition before installation of condenser at Sterling

Meter does not respond to momentary voltage changes. Multiplier: 1,200

a load factor of 50 per cent or more, the flywheel, of course, is of no benefit. To supply the load under consideration, a motor generator set would need to be at least 20,000 kva in capacity, which would be quite expensive. In addition to its high cost, the voltage regulation on the bus supplying the furnace would be very unsatisfactory. It would certainly be less satisfactory than that obtained with the transformer connected to the high-voltage system.

A series booster, connected as shown in figure 6, was considered as an inexpensive

solution. This series booster would have its exciting winding in series with the supply to the furnace load; its booster winding would be between the 13.8-kv bus and the supply to the mill and lighting load. This would improve the voltage for the general service, but would

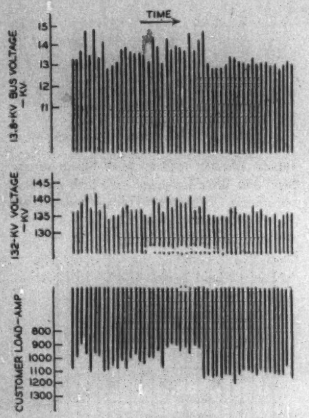

Figure 5. Oscillograms of typical changes in arc-furnace load and effect on bus voltage—no reactor, no condenser

C-phase records taken at Sterling (see figure 2)

Top—13.8-kv bus voltage
Center—132-kv voltage
Bottom—customer load current

To obtain an accurate measurement of the variations in voltage with variations in load a very large deflection was used on the voltage elements of the oscillograph. However, with this large deflection the waves from the various elements would interfere on the record and a special technique was used so that only the top of each oscillograph wave was recorded, the balance being blocked off. This accounts for the unusual appearance of the oscillograms. Space did not permit a more detailed explanation of the technique for obtaining partial oscillograph waves

make the furnace regulation poorer and would not improve the voltage for the other Illinois Northern Utilities Company customers.

Another scheme considered was that of series capacitors. These could be connected in the supply transformer secondary leads or in the 132-kv line, or divided in two parts and connected in both places. A series capacitor will neutralize a part of the reactive load due to the line and transformer reactance. The capacitor could be made large enough to maintain practically constant voltage on the furnace bus, but it would not improve regulation on the Dixon 132-kv bus. Since the electric furnaces are subject to frequent short-circuits the series capacitors would require suitable protection against damage from this source. There was also a possibility of telphone interference, as series capacitors will tend to accentuate rather than reduce the effect of harmonic current.

Condenser Installation

The solution which promised to solve the regulation problem for this customer and the general system and the one finally adopted was the installation of a 20,000-kva synchronous condenser connected to the 13,800-volt bus at Sterling which supplies the furnace load. This con-

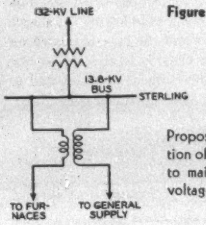

Figure 6. Series booster

Proposed connection of series booster to maintain constant voltage on general supply

denser was designed with somewhat special characteristics to obtain the maximum benefit for this application.

The synchronous condenser is useful for such an installation as this in three different respects. First, the synchronous-condenser output improves the system power factor, which in turn is of benefit in improving voltage regulation and reducing transmission losses. Second, with gradual variations in load the synchronous condenser can maintain constant voltage on the customer's bus by the action of an automatic voltage regulator. Third, with instantaneous changes in load the inherent characteristics of the synchronous condenser tend to limit the voltage change and thereby reduce lamp flicker, before the voltage regulator has had time to take effect. This is accomplished because of the instantaneous change in output of the condenser which takes place with a sudden change in terminal voltage. Fortunately, the action of the condenser in maintaining constant system voltage also tends to maintain a satisfactory system power factor.

Since the voltage dips on the 132-kv system are proportional to the reactive kilovolt-amperes supplied from this system to the furnace load, it was possible to decrease the flicker on this system by transferring the greater part of the sudden changes in reactive load to the synchronous condenser. This was accomplished by the insertion of a special buffer reactor between the 13.8-kv secondary winding of the 132-kv transformer bank and the bus to which the synchronous condenser and the furnace load are connected. This reactor was equipped with taps so that the amount of reactance could be varied after installation in order to use the value which would transfer the maximum reactive kilovolt-ampere load fluctuation to the synchronous condenser without causing trouble from surging of the condenser. A short-circuiting breaker was installed to take the reactor out of service at any time that the condenser or furnaces are not operating.

Table I shows a comparison of the calculated benefits obtained by the vari-

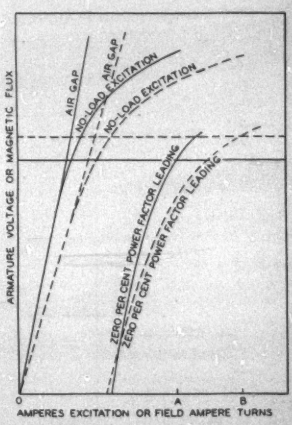

Figure 7. Synchronous-condenser saturation curves

Comparative saturation curves of synchronous condenser with normal design and special design for this application. Solid lines show normal characteristic and dashed lines show characteristic with increased air gap and higher flux density in armature

ous corrective means described. This tabulation indicates not only the extent of the voltage dips with a given change in load, but also the resultant reactive load which the system must supply with the corrective device in service.

The actual flicker without any correction was greater than that calculated.

Table I. Methods of Correcting Voltage Flicker

Calculated Effect of Various Means Proposed to Reduce the Voltage Flicker Caused by Instantaneous Load Changes on Electric Arc Furnaces. Balanced Three-Phase Load Assumed Although Most Instantaneous Swings Are Unbalanced

Corrective Equipment	Voltage Fluctuation in Per Cent for Instantaneous Swing of 10,000 Kva at 75 Per Cent Power Factor		132-Kv Reactive Load on System for Steady Customer Load of 20,000 Kw at 80 Per Cent Power Factor (Kilovolt-Amperes)
	Sterling 13.8 Kv	Sterling 132 Kv	
No corrective means	8.2	3.6	19,300
10,000-kva condenser, no reactor	5.3	2.5	7,900
20,000-kva condenser, no reactor	4.2	2.0	2,100 leading
10,000-kva condenser, 40 per cent reactor (20,000 base)	10.1	1.8	16,300
20,000-kva condenser, 40 per cent reactor	6.7	1.2	6,300
20,000-kva condenser, 20 per cent reactor	5.8	1.5	2,100
20,000-kva motor generator set	9.9		
10 per cent series capacitor (20,000 base)	4.6	3.5	15,400
Booster transformer	0* 9.0**	3.7	20,000

* General power supply. ** Supply to arc furnaces.

These differences are due primarily to the fact that the increment loads involved in the sudden changes in load are at very low power factors. Also, the sudden changes are usually single-phase changes, while the calculations are based on a three-phase load. By observation of lamp flicker, which is the final measure, the improvement due to the condenser is appreciably better than expected from calculations.

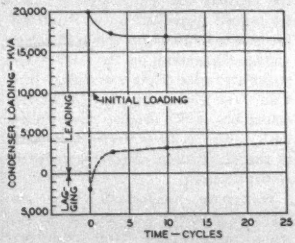

Figure 8. Condenser performance curve

Calculated performance of 20,000-kva synchronous condenser, excited for 10,000 kva at normal voltage. The solid line shows the change in output when the terminal voltage is suddenly dropped ten per cent. The dashed line shows the change when the terminal voltage is suddenly increased ten per cent. Both curves are based on constant exciter voltage

Condenser Design

The synchronous condenser was designed especially to meet the demands of this rapidly fluctuating load. It is necessary for the condenser to produce a large change in reactive kilovolt-amperes for a given variation in voltage. This may be accomplished by designing the machine so that the effective saturated values of subtransient and transient reactances are low. For an application of this kind, the amount of saturation that is effective is not the usual "rated voltage" value of reactance (that is, the reactance effective on short circuit from rated voltage and no load) but is a considerably lower value because the internal voltage is appreciably above normal and consequently the saturation is greater than at normal voltage. The manufacturer's tests and calculations for this machine indicate that the "rated voltage" saturation factor for transient reactance is about 0.91, while the saturation factor effective at full load during small voltage changes is about 0.67. The low reactances and saturation factors in this case were produced by working the machine at fairly high magnetic densities, increasing the saturation of the various parts, and increasing the air gap.

Figure 7 shows characteristic curves for a condenser of normal design compared with one having these special features. In this figure, the solid lines show the no-load and full-load saturation curves for a normal condenser design and the dashed lines are the characteristics for this condenser. It should be noted that the increased gap requires greater excitation for a given terminal voltage or armature flux density. Furthermore, the machine works at an increased armature flux density and this results in further increased excitation for the full-load point. *OA* represents the field excitation for full load and normal voltage on a standard machine and *OB* is the excitation on this machine for the same condition. Obviously, this increased field will result in better voltage regulation.

The result of these changes was a machine with an unsaturated subtransient reactance of 22 per cent, an unsaturated transient reactance of 30 per cent, and a synchronous reactance of 124 per cent. These subtransient and transient values were checked by an oscillograph test after installation.

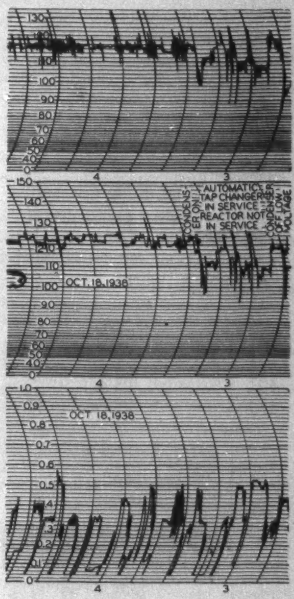

Figure 9. Effect of synchronous condenser on voltage regulation

Sections of three simultaneous graphic charts at Sterling to show benefit of condenser. No condenser and no reactor from 2:45 to 3:25 p.m. Condenser in service with 20 per cent reactor after 3:25 p.m.

Top—13.8-kv bus voltage × 120
Center—Transformer secondary voltage × 120
Bottom—Customer kilowatt demand × 39,000

Figure 8 was drawn to illustrate the calculated performance of this synchronous condenser for a sudden change in terminal voltage due to a sudden change in the customer's reactive load. This curve shows the variation in condenser loading with respect to time, on the assumption that a ten per cent change in terminal voltage is applied while the condenser is excited for 10,000 reactive kva loading at normal voltage. The instantaneous

change in output for a ten per cent change in voltage is at least 10,000 kva.

Results Obtained

The improvement in regulation is well illustrated in the charts of figure 9. These charts are a short section taken under a typical load condition. The charts illustrate a brief period during which the condenser was out of service and the reactor short-circuited; followed immediately by a period with the condenser and reactor in service. The comparison is therefore under directly similar load conditions. The beginning of each chart is representative of conditions before the installation of the condenser, and the remainder representative of the present conditions. The graphic charts, of course, are not capable of showing either load or voltage changes which take place in a small fraction of a second. Such sudden changes are shown in the oscillogram of figure 10, which was also taken with the condenser in operation, and with a 20 per cent reactance between the condenser bus and the 13.8-kv secondary of the main transformer bank. The complete oscillograms contain records of 12 elements, showing the currents and voltages on all phases. The records from the other elements were less satisfactory and were not reproduced because they do not add to the clarity of the picture. The bottom record on the oscillogram is good for comparative purposes only. It was obtained from a single-phase watt element in the oscillograph. This element records the product of current in one phase, and a voltage which is 30 degrees out of phase with this current. Its record serves to show the nature of the power swings of the condenser.

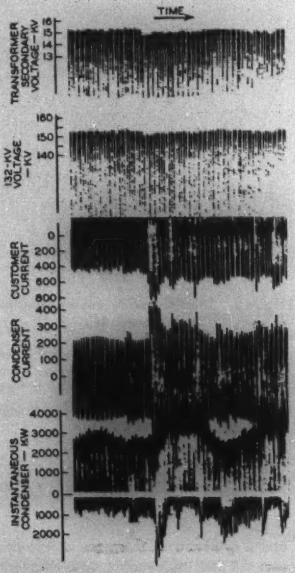

Figure 10. Oscillogram of condenser operation with 20 per cent reactor—effect of sudden change in load current on bus voltage and condenser loading

Reading from top to bottom, records are from elements at following points at Sterling (see figure 2)

1—Transformer secondary voltage
2—132-kv system voltage
3—Amperes in supply to customer
4—Amperes in synchronous-condenser leads
5—Instantaneous watts; product of condenser phase current and voltage between phases

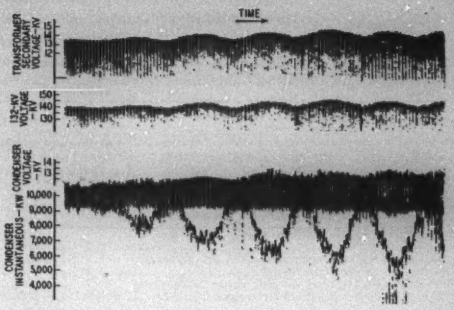

Figure 11. Oscillogram of condenser operation with 40 per cent reactor—voltage oscillations on high-voltage system caused by condenser swinging

Reading from top to bottom, records are from oscillograph elements at following points at Sterling (see figure 2):

1—Transformer secondary voltage
2—132-kv system voltage
3—Sterling bus voltage
4—Instantaneous watts; product of condenser phase current and voltage between phases

An attempt was made to get the maximum benefit of the condenser in smoothing out the system voltage by using a 40 per cent reactance between the transformer and the condenser bus. This increased reactance was effective in further reducing the voltage flicker caused by the load changes, but resulted in hunting of the condenser with respect to the remainder of the system. A series of rapid load changes may be timed in such a manner as to have a cumulative effect if the reactance between the condenser and the system is too high. In a few instances, with the 40 per cent reactor, this cumulative effect was sufficient to cause the condenser to pull out of step and trip off the system.

The oscillogram of figure 11 illustrates a typical case of condenser hunting. This shows the steadily increasing swing in the loading of the condenser. The single-phase watt element of the oscillograph is again connected in such a way as to measure the product of the amperes in one phase of the condenser and a voltage 30 degrees out of phase with this current. Only the top half of this record is reproduced, because the bottom half on the original film was not clear enough for printed reproduction. It is interesting to note that hunting results in greater voltage fluctuations on the primary and secondary sides of the transformer bank than those which took place on the condenser bus, which supplies the customer load. This can be explained by a study of the distribution of reactance on the system diagram.

Wave-form oscillograms were also taken on customer load and on the system voltage. These oscillograms are not reproduced here, but they show that the original wave form was bad, and that the synchronous condenser was effective in improving this wave form to the extent that it should cause no telephone interference. It is also interesting to note that the lighting load was reconnected to the main 13.8-kv supply on October 27, 1938, after the condenser was placed in service and that satisfactory operation of the sensitive mercury-vapor lamps is now obtained from that source. It had been impossible to operate these lamps satisfactorily from the 13.8-kv source before the installation of the condenser.

Cost and Benefits

The installation of this synchronous condenser was not particularly cheap. However, the total cost was under $10 per kilowatt of integrated maximum demand. This cost is considered reasonable

when it makes possible the supply to such a load without noticeable disturbance to other customers. In addition to its primary function of correcting the voltage flicker, the condenser is desirable for the following reasons:

1. Excessive maintenance of the transformer tap-changers is eliminated.
2. The load power factor is corrected to approximately unity.
3. Transmission losses are reduced.
4. The stability limit of the 132-kv system is raised.
5. The Dixon load can be carried from Powerton or Waukegan alone, without running Dixon steam generators, if one 132-kv line is out.

Conclusion

The installation of a suitable synchronous condenser proved to be an excellent remedy for voltage flicker caused by severely fluctuating load on a 132-kv overhead transmission line. The cost of the remedy at $10 per kilowatt of arc-furnace load was more than justified because it resulted in better system operation, in addition to making the supply to this class of business possible, without disturbance to other customers. This type of load, while it has wide instantaneous swings, has a very satisfactory load factor throughout the 24-hour period. Such loads should be encouraged by power companies.

Discussion

W. B. Wallis (nonmember; Pittsburgh Lectromelt Furnace Corporation, Pittsburgh, Pa.): It is noted with interest that the furnace load in question consisting of two high-power rolling-mill-type electric furnaces rated at six tons each are connected to the center of a 220-mile 132,000-volt 60-cycle transmission line, along with various power and lighting loads and the lighting voltage flicker has been neutralized.

As the author states, arc-melting-furnace load of this character is one of increasing importance as a matter of large revenue to the power companies and is interesting in that it shows an economical solution of voltage fluctuation due to the results of high peak loads on a very long transmission system serving many small lighting communities.

These furnaces while rated at 7,500 kva each, are habitually overloaded and are frequently run with a load of 16,000 kva each. While they were rated at 6 tons they regularly make heats ranging from 22 to 24 tons. The installation of the furnaces in this plant is a distinct commercial success, making high-grade steel ingots from ordinary country scrap at a price well below the established market for billets of similar size. Indeed the demand for the steel has been such that the furnaces have necessarily been enormously overloaded to get out the necessary production.

The power bills for this customer's 18,000 to 19,000-kw load average $40,000 to $44,000 per month which constitutes a very attractive source of revenue to the power system.

The more than 100 per cent furnace overload naturally imposed conditions on the power company that were not originally considered in the power service calculations. The installation of the 20,000-kva synchronous condenser with its voltage regulator is an ingenious and interesting installation, and the fact that this together with the switchgear and reactors has resulted in an entirely satisfactory solution of the difficulties originally encountered is a subject for congratulation to the engineers who conceived and carried out the work. This is especially true in view of the fact that the cost was very moderate and the remedy so complete and all under very unusual conditions caused by the extra long length of transmission line.

The commercial success of this plant will no doubt result in the installation of a number of other similar arc-furnace rolling-mill plants and the solution will unquestionably be of interest to prospective suppliers of such large load and revenue.

It might also be noted that if a separate line had been run from Dixon to Sterling to carry the lighting load that perhaps no very great objection would have been found to the furnace load, even though much larger than originally considered due to the unusually large overloads imposed.

The power-factor conditions are quite satisfactory for the load in question, as is also the load factor, all of which will no doubt encourage other installations of a similar character.

Sterling Beckwith (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): Mr. LeClair's paper is very interesting and shows the logical solution of a difficult problem. As a machine designer I would like to emphasize the utilization of saturation in the condenser to improve its characteristics for this application. When saturation of transient reactance is ordinarily thought of, the saturated value, or what has more recently been called the rated voltage value, is taken as the effective value for a dead short circuit from rated voltage. This rated voltage value has developed for use in studies of system short-circuit currents. However, for a case such as the one discussed by Mr. LeClair, the value of transient reactance that should be used to calculate the transient voltage dips is a value which is more saturated than the rated-voltage value used in studies of short-circuit currents. The reason is that the machine is initially operating at half to full load, so that the internal voltage of the machine is greater than unity.

Mr. LeClair gives the rated voltage saturation factor as 0.91, and the saturation factor effective at full load during small voltage changes as 0.67, which shows the pronounced gain from saturation. It also shows that ordinary characteristics of an alternator, such as short-circuit ratio, synchronous impedance, or even rated-current or rated-voltage values of transient reactance will not give a direct measure of the stability of a machine for service such as that described by Mr. LeClair.

It would be interesting to know the per unit resistance of the system plus transformers plus reactors, since this resistance is one of the important factors contributing to the hunting that was observed when 40 per cent reactance was used. It might also be interesting to know the relation between the peak load at the Sterling bus and the steady-state power limit at this bus, both with and without the 20 per cent and the 40 per cent reactors.

Figure 1 accompanying this discussion shows the connections used to test the voltage dip of a large condenser under sudden load changes starting from an initial condition of full load. Curves taken from oscillograms made during such a test are shown in figure 2 of this discussion.

Curve A is the per unit voltage, and curve B is the per unit current. It should be noted that both contain a subtransient portion lasting about 0.05 second and a transient portion which lasts beyond the end of the oscillogram. The third curve of this figure shows the ratio of the change in voltage to the change in current, or in other words the reactance effective during the voltage change (since $R = E/I$). The subtransient and transient effects are even more pronounced in this curve than in the others. For purposes of comparison, the test values of saturated and unsaturated reactances are shown by arrows. These test values were obtained by sudden short-circuit from no load, and the saturated values correspond to short-circuit at an initial voltage exactly equal to the internal voltage (= voltage behind Potier reactance) existing in curve A prior to the sudden change in load. The change from a subtransient to a transient to a saturated synchronous reactance is so striking and clear that further comment is unnecessary. Also the agreement with the actual numerical value of the reactances as deter-

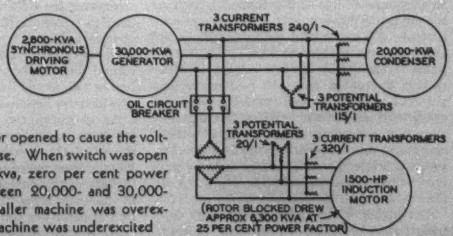
2,800-KVA SYNCHRONOUS DRIVING MOTOR
30,000-KVA GENERATOR
3 CURRENT TRANSFORMERS 240/1
20,000-KVA CONDENSER
OIL CIRCUIT BREAKER
3 POTENTIAL TRANSFORMERS 115/1
3 POTENTIAL TRANSFORMERS 20/1
3 CURRENT TRANSFORMERS 320/1
1500-HP INDUCTION MOTOR
(ROTOR BLOCKED DREW APPROX 6,300 KVA AT 25 PER CENT POWER FACTOR)

Figure 1. System on which tests were made

Oil switch was closed or opened to cause the voltage to suddenly fall or rise. When switch was open approximately 10,000 kva, zero per cent power factor, circulated between 20,000- and 30,000-kva machines. The smaller machine was overexcited, and the larger machine was underexcited

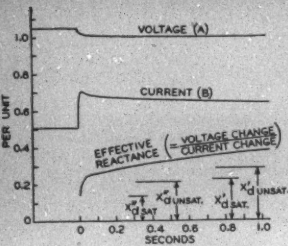

Figure 2. Results of voltage-dip tests

mined by usual methods and here shown by the arrows is very good.

B. M. Jones and **V. E. Hill** (nonmember; both of Duquesne Light Company, Pittsburgh, Pa.): We electric utility people had just as well recognize that large electric furnaces are part of our business—some of our bread and butter—and we must make up our minds to learn how to handle them so that we can live more peacefully.

As we all know, the difficulty in serving large electric arc furnaces is that the large load swings at low power factor may cause objectionable voltage fluctuations to other customers in the same area, and expensive corrective measures may have to be taken.

Obviously, the correct engineering approach is to determine in advance what the power swing and resultant flicker will be, and to provide a suitable system connection and corrective equipment, if necessary, to keep the flicker within tolerable limits. However, this is not always so easy, for in some cases it is very difficult, if not impossible, to find out just what the electric performance of the furnace will be, due, we believe, to the fact that the manufacturers of the furnace cannot determine themselves in advance the exact electrical performance and characteristics of the complete furnace installation.

In a recent installation, certain system changes and switching during the melt-down period were necessary after the furnace installation was made, to prevent the flicker from being reflected into parts of our system where it would be objectionable. This furnace caused much larger swings than had been anticipated as a result of our experience with other furnaces and from what we had been led to believe would exist as shown by literature on this subject. Tests of these swings, both by recording meters and oscillograph, indicated frequent single-phase swings of 300 amperes, with a maximum of 400 amperes, which is equivalent to 8,500 kva or, for such currents in all three phases, is equal to 14,000 kva, three phase. The 22-kv supply voltage at this station fluctuated as much as four to six per cent, with occasional variations as high as eight to ten per cent. These fluctuations were also experienced, of course, at other customers and distribution stations in this vicinity, while there was a two to three per cent voltage fluctuation on the 22-kv bus of the transmission supply substation.

The higher fluctuations on the 4-kv distribution substations within the vicinity of this customer gave rise to a few flickering-light complaints, in the order of four or five a month, which is remarkably small in view of the magnitude of the swings and the thousands of customers exposed. However, another objection to these voltage fluctuations from a company standpoint was the excessive number of regulator operations caused thereby. Counters placed on some of the regulators in nearby distribution substations indicated that, whereas only 4 to 6 operations per hour were experienced when the furnace was not running, from 200 to 300 operations per hour occurred when the furnace was on, that is, during the melting-down period. A maximum of 1,000 operations per hour was noted on one occasion; this based on only a 15-minute period.

Other distribution substations fed from this same transmission substation, but not by the same lines feeding the furnace, also experienced an increase in regulator operations, but not nearly so many. Checks on one regulator indicated 50 to 150 operations per hour with the furnace on, whereas the normal number with the furnace off was generally less than 30 per hour. Obviously, such an increase in regulator operations would enormously increase the maintenance on them.

Even though the number of complaints was relatively few, it was evident that something had to be done. One or more new 22-kv lines into this area were considered, but needless to say, the cost would have been entirely unjustified, as would also have been the installation of a synchronous condenser. Since the voltage fluctuations back at the transmission substation were tolerable, the obvious solution would have been a separate line to serve this furnace only, but this, too, would have been very expensive. However, the same objective was accomplished by another means. Since this customer was the first load fed from his direct line, supervisory equipment was installed so that the breaker at his station could be opened by remote control from the transmission substation, thus leaving him fed radially on this one line. This move was accomplished at a cost of only $4,400.

It is true that the opening of this breaker reduces the normal capacity to this area, or rather the number of feeds to this district, since the customer's load utilizes a good portion of the normal line capacity. The breaker is only open a very small percentage of the time, because the furnace is not operated continuously—generally, only 15 or 20 heats a month and not more than one a day. Furthermore, the breaker can be instantly closed and the line returned to service in this district during any emergency periods, such as arises during lightning storms or for failure of other lines in this district. Should this customer ever operate the furnace continuously, one or two shifts each day, or if the load in this district should materially increase, then another line or two would be needed and could then probably be justified.

As concerns the enormous number of regulator operations, the breaker opening described above reduces the severity of the voltage fluctuations of the stations in the vicinity of this customer to that experienced at the supplying transmission substation, two to three per cent. Even these fluctuations were objectionable and so our substations department developed a time-delay device to attach to the regulators. These devices permit of the normal functioning of the regulators to adjust for bus-voltage variations, load changes, and the like, but prevent the regulators from attempting to follow the rapid fluctuation caused by the furnace.

We have conducted negotiations from time to time on other large furnace installations, up to 10,000 and 12,000 kva, in which we considered service at 66 kv, and also the use of corrective equipment, such as referred to in Mr. LeClair's paper.

It has also been our experience that the size of the power swings caused by electric arc furnaces is subject to appreciable control by the furnace operator, through the choice of the voltage tap used, the length of arc, and general skill developed from experience.

The electric utilities should, we believe, protect themselves from these objectionable voltage flickers when they interfere with the service to other customers, probably by charging against the furnace job the expense of major system rearrangement, new lines, or corrective equipment, all of which may be necessary to hold fluctuations within tolerable limits. In this connection, it is highly desirable and has been our experience, that it is to the mutual benefit of all concerned for the utility, customer, and furnace manufacturer to co-operate and work together in the initial design and in the operation of the furnace.

L. W. Clark (The Detroit Edison Company, Detroit, Mich.): Most power companies at some time or another have encountered similar service problems involving electric arc furnaces as that described and thoroughly analyzed by Mr. LeClair. There are always several ways in which the load can be handled and it is usually a matter of economics as to which method is finally selected. This installation is of particular interest in that the analysis shows a synchronous-condenser installation to be the most satisfactory solution.

In general, our experience has indicated that a synchronous condenser would not improve a flicker condition sufficiently to warrant the installation from the standpoint of flicker elimination alone. There usually had to be some other need for the condenser, such as general voltage control of that part of the system before its installation could be justified. No doubt these other advantages were deciding factors in the selection of a condenser for this particular installation. The original flicker condition was not beyond the range of correction afforded by the condenser operation as shown by the reduction of flicker from 3.6 per cent to 1.5 per cent.

Where the voltage fluctuation or flicker must be corrected to a greater extent, for instance, in the range of eight to one, it is doubtful if a condenser installation would prove economical as compared with a motor generator set. As an example, an installation of two small single-phase arc furnaces at Vassar, Mich., as shown in figure 1, illustrates both the motor-generator-set and the synchronous-condenser method of solution. The smaller furnace rated 250 kw, 360 kva, has maximum instantaneous load fluctuations of about 500 kva, and was

served from the 4,800-volt synchronous-condenser bus. Calculated voltage fluctuations on the 4,800-volt bus due to the furnace operation are 4.8 per cent with the condenser shut down, and 3.2 per cent with the condenser operating. This is a standard design of synchronous condenser with a subtransient reactance of 24 per cent and a synchronous reactance of 164 per cent. Taking into account that there is no buffer reactor to force the condenser to absorb more of the reactive kilovolt-amperes, the reduction in voltage fluctuation is of about the same order as that of the Sterling installation described by Mr. LeClair. As long as there was no general lighting load served from this bus, the voltage conditions were satisfactory as the flicker in the main 24-kv bus was not objectionable under normal operating conditions with both 24-kv lines in service. However, it later became necessary to transfer lighting load to the 4,800-volt bus and then, even with the condenser in operation, the flicker proved annoying and caused the furnace load to be transferred to a motor generator set on the other bus.

The motor generator set consisting of a 1,750-kva 80-per-cent-power-factor synchronous motor driving a 600-kw generator was originally installed to handle a 600-kw 875-kva single-phase furnace which has maximum load fluctuations of about 1,300 kva, or about $2^1/_2$ times those of the smaller furnace, and would cause a flicker of about 12.5 per cent on the bus if corrective measures were not applied.

It is obvious that a condenser installation of sufficient size to reduce the 12.5 per cent flicker to something in the order of 1.5 per cent to 2 per cent, would not only be expensive but it would also be of much greater size than could ever be used or needed for general voltage control of that portion of the transmission system. However, the motor generator set, which has a slightly lower installed cost than the 3,000-kva condenser on the opposite bus, does reduce the flicker to less than 2 per cent, and tests show the set to be about $5^1/_2$ times as effective in flicker reduction as the more costly 3,000-kva condenser.

The paper mentions the fact that for a load with a very short-time characteristic, such as a resistance-welding machine, a motor generator equipped with a flywheel and using an induction motor is satisfactory but that for a furnace load with the greater load factor, the flywheel would be of no benefit. It is our opinion that we might go a step farther and state that a flywheel set need only be considered on loads with a high fluctuating kilowatt demand, such as rolling-mill loads, but that for either welder loads or arc-furnace loads in which the predominating source of trouble is the rapid change in reactive rather than kilowatt load, the flywheel type of set is not generally needed. A straight, synchronous set will do a very good job where the desired reduction in magnitude of voltage fluctuation is not greater than five or ten to one.

It is interesting to note that the furnaces apparently operated for some time prior to the condenser installation and, consequently, imposed annoying flickers on the 132-kv system which would affect the local lighting load at Dixon. While these flickers, no doubt, only occasionally reached the maximum value of 3.6 per cent, there probably were frequent flickers of sufficient magnitude to affect the lighting, and we would be interested to know if many customer complaints were received during this period.

H. P. St. Clair (American Gas and Electric Service Corporation, New York, N. Y.): Mr. LeClair has described in his paper a truly difficult problem of voltage regulation. Problems of this type are encountered now and then, probably with increasing frequency as time goes on, and Mr. LeClair's paper describing the solution in his particular case will undoubtedly be of value to many other engineers faced with the necessity of working out voltage regulation problems of a similar nature in the future.

I should like to describe briefly a somewhat similar problem which was encountered on the system with which I am associated and the solution which was used to take care of it.

At St. Joseph, Mich., the Auto Specialties Manufacturing Company, operators of a foundry and a machine shop, had installed several electric furnaces, one of which was nominally rated at 5,000 kva, but actually used at a much higher rating. This customer's load, including the large furnace, was supplied over a separate double-circuit 27-kv line from the Riverside substation which in turn was supplied by a 37,500-kva transformer bank, stepping down from a double-circuit 132-kv line 38 miles in length from the Twin Branch generating plant and substation. This transformer bank was equipped with a tertiary winding to which was connected a 15,000-kva transformer condenser arranged to regulate voltage on the 27-kv bus. In addition to the Auto Specialties Manufacturing Company's circuits, this substation also supplied a 27,000-volt system, including the cities of Benton Harbor and St. Joseph.

This arrangement was expected to be entirely adequate to handle the fluctuating industrial load in this area without difficulty and as a matter of fact for several years voltage fluctuations did not become critical. However, as the Auto Specialties Manufacturing Company's operations increased, accompanied by more intensive use of the large electric furnace, severe voltage fluctuations were encountered in the adjacent area supplied from the Riverside substation 27-kv bus. Observations at this time indicated that the electric-furnace load was imposing on the system swings as high as 15,000 kva, the increments in these swings being largely reactive kilovolt-amperes. Visible fluctuations of four to five volts were observed on the Riverside substation 27-kv bus, with nearly two volts visible on the 132-kv bus. Obviously, the synchronous condenser offered very little help since the power swings were entirely too fast to be followed by any condenser and regulation scheme.

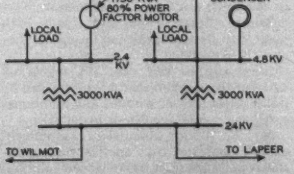

Figure 3. Vassar substation

Since the power and reactive kilovolt-ampere swings were actually producing voltage fluctuations in excess of five volts, it seemed almost obvious at the outset if we were to continue to serve this customer's load, a different arrangement would be necessary. Calculations indicated that a separate transformer, stepping down from 132 kv to 27 kv to supply this customer's lines alone would reduce fluctuations on the 132-kv bus to less than two volts; and with the synchronous condenser operating on the 27-kv bus from which the remainder of the system load was supplied, the regulation on that bus would be still better than on the 132-kv bus. Consequently, a new 15,000-kva transformer bank was installed and the heavy swings of this particular customer were as you might say "quarantined" in this manner, so that service could be supplied to the remaining area without intolerable voltage fluctuations.

Comparing this setup with that described by Mr. LeClair and illustrated in figure 2, of his paper, it might be pointed out that Mr. LeClair was fortunate in having the local distribution load at Dixon supplied directly from the 132-kv system, so that he was not faced with the problem of supplying any other load except the customer's load from the low side of the transformer bank at Sterling. In effect, the solution which we adopted was to change over to a system more nearly like that shown in figure 2 with the local distribution system separated from the furnace load.

G. B. Schneeberger (Cleveland Electric Illuminating Company, Cleveland, Ohio): Mr. LeClair's paper is a very interesting and detailed description of the problems arising in connection with the operation of an arc furnace especially when the furnace is used to melt cold metal.

This type of load is inherently very erratic and demands careful consideration before it is connected to any system, or overworked regulators and flicker complaints will result.

The great improvement in refractories has enabled operators to push their furnaces far beyond their original capacities. This has resulted in an insistent demand for more power. The nominal rating of a furnace is on a par with the nominal rating of welders. It is not uncommon to encounter furnaces which have doubled their original transformer capacity. In one case on our system, a furnace whose original transformer equipment was 375 kva is now operating with 1,200 kva.

This emphasizes the necessity of allowing a liberal margin when this type of load is under consideration.

It is interesting to note the application of the synchronous condenser in handling the unusual *lagging* reactive kilovolt-amperes. With the advent of the modern strip mill, due to the liberal use of synchronous motors, troublesome *leading* re-

active kilovolt-amperes was encountered. The synchronous condenser was also used to advantage to correct this condition. Most of the more modern mills are now provided with regulators which control the reactive condition at its source.

E. S. Fields (Cincinnati Gas and Electric Company, Cincinnati, Ohio): The AIEE paper entitled "Arc-Furnace Loads on Long Transmission Lines" has been read with a great deal of interest. The various solutions considered and the one finally adopted along with the special characteristics of the synchronous condenser are to my mind distinct contributions in the field of electric-system engineering.

From my knowledge of the rate per kilowatt-hour to make electric melting attractive and the large amount of system investment to serve this customer, it is quite apparent that the customer must have a very high annual load factor to make the service mutually attractive financially. I imagine that some of the five items of benefits listed in the paper were substantial, particularly item 5 which represents a release of transmission capacity, and that the evaluation of these items went a long way toward justification of the expenditure.

While we have no such problem, as the one you describe, on our system, we have one that has some of the same elements in which you may be interested. It is a large steel rolling mill located about 40 miles from our power stations and served from 66-kv lines which also supply the usual types of system load at the same locations. The variations in the steel-mill load are as much as 25,000 kw in a short interval of time and, since a great part of this load consists of synchronous-motor-driven motor generator sets, automatic field control has been applied to these motors to vary the field strength with the load. The application has given entire satisfaction.

T. G. LeClair: Mr. Wallis has offered some valuable additional information on the characteristics of these particular electric furnaces. The characteristic which he mentions of severe overloading has been found to apply to not only this furnace installation, but also to a large number of others. The statement made by Mr. Wallis that there would have been no objection to the furnace load if the lighting load had been on a separate line is not quite correct. He has evidently been misinformed, because the lighting load at Sterling was connected through separate lines to the Dixon 33-kv bus during the time of greatest disturbance. The original disturbance was, in fact, noticeable throughout the territory served from the Dixon substation.

The comments by Mr. Beckwith are an important contribution from the designer's viewpoint. They show that with a reasonable foreknowledge of the problem much can be done to adjust a synchronous condenser to be more beneficial in handling of disturbances caused by fluctuating loads. In answer to his question, the resistance of the system to the condenser bus is 1.3 per cent on a 20,000-kva base with either a 20 per cent or a 40 per cent reactor. The system's reactance to the condenser bus is 42 per cent and 62 per cent with the 20 per cent and 40 per cent reactors, respectively.

Mr. Beckwith's question concerning the steady-state power limit at the Sterling bus is quite pertinent. The calculated pull-out limit is 32,000 kw with 40 per cent buffer reactor, 47,000 kw with 20 per cent buffer reactor, and 90,000 kw with no buffer reactor.

The discussions by Mr. Clark and by Messrs. Jones and Hill show radically different solutions for the intermittent-load problem. In both of these cases the synchronous condenser described in the paper would not have been the most satisfactory solution. The size of the loads, their location on the system, and the annual load factor all apparently had a bearing in coming to a different conclusion.

Messrs. Schneeberger and Fields both point out that intermittent loads are frequently associated with synchronous machinery and in this case the regulating value of the synchronous machinery can be taken advantage of without any additional cost for a special condenser installation.

Mr. St. Clair's discussion, surprisingly enough, indicates that another furnace installation called for a rather similar solution, even though the problem was approached from the opposite angle of having the condenser already in service and installing the line to make the condenser more useful.

The variety of solutions for the problem of intermittent loads which have been mentioned in the discussions accentuate the note on which I would like to close this discussion. That is that every intermittent load appears to have certain special characteristics and is applied to a power supply system with different limitations. Therefore, there appears to be no general answer to the question of what is the best method of supplying these intermittent loads.

Intermittent equipment is a growing essential tool to the industrial user. Unquestionably, the power companies should stand ready to supply these intermittent loads. The greatest benefit can be obtained by whole-hearted co-operation between the equipment designer, the equipment user, and the utility company *before* the order is placed. Adjustments in the design of the equipment or the proposed methods of operating may frequently result in lessening the possible disturbances to the point that the intermittent equipment can be installed without expensive special facilities to be paid for either in the rate or as a separate charge.

Mercury-Arc Rectifiers in the Coal-Mining Industry

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ALTHOUGH mercury-arc rectifiers at present constitute only a small part of the total installed capacity of a-c to d-c conversion equipment in coal mines, in the past three years 21 rectifiers of a total rated capacity of 8,100 kw have been placed in service in 15 coal mines. Considered alone, this would not be important, but, since these rectifiers exceed in number of units and capacity other forms of new conversion equipment installed in the same period, a definite trend toward the use of rectifiers is indicated. It is the purpose of this paper to discuss the causes for this trend and to record, in so far as it is possible, the results which have been obtained with rectifiers in mining service.

Two developments are responsible for this interest in rectifiers. First is the increasingly rapid change from hand loading methods to concentrated operation with machine loading. If the large investments in mining machines required for mechanical mining are to be profitable, these investments must be backed up by a power supply which is efficient and which is adequate to supply an uninterrupted flow of power to the mining machines.

The second is the development of the ignitron rectifier which can be used advantageously for 275-volt service and for higher voltages. Prior to 1936, only the tank-type or multianode rectifier was available for which the principal field of application is at 500 volts and higher. Since, by far, most of the coal is produced by 275-volt mines, it was not until the ignitron was developed for large capacity that rectifiers really became available to the coal-mining industry as a whole.

The beginning of the modern trend to rectifiers is marked by the installation of a 600-kw 600-volt tank-type rectifier by Pittsburgh Coal Company in August 1936. This was discussed by A. Lee

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Barrett at an AIEE District meeting in Akron, Ohio, in October 1937. Briefly, Mr. Barrett stated that this unit is saving 26.5 per cent of its cost per year due to increased efficiency. The rectifier serves a mine working three shifts per day and 600 shifts or more per year.

The year 1937 saw two installations which produced several "firsts". In February, the Union Collieries Company of Pittsburgh placed a 300-kw 275-volt d-c, 2,300-volt three-phase 60-cycle ignitron equipment in an underground station, approximately two miles from the shaft bottom. This equipment may be briefly described as consisting of an automatic control, an Inerteen-filled transformer, a six-tube ignitron rectifier, and a water-to-air heat exchanger for cooling the rectifier. Because of clearance conditions in the main haulage way, the maximum height of any part is 55 inches, and the maximum width 62 inches.

In October 1937, the Weirton Coal Company installed three portable ignitron rectifiers to be the first mine:

1. To be served solely by rectifiers.
2. To use portable rectifiers.
3. To make all their substations portable.
4. To place all their conversion equipment underground.

This equipment is essentially the same as the Union Collieries Company equipment, except that it is mounted on three trucks. The transformer and a-c switchgear are on one truck, the rectifier and its auxiliaries and the heat exchanger on the second, and the d-c switchgear on the third.

Installations in 1938 followed essentially the pattern established in 1937.

In 1939, two noteworthy advances have been made. Three 600-volt ignitron rectifiers have been placed in service, all of these being of the nonportable type in surface substations.

The second innovation, which may be the more important, is the use of permanently evacuated, permanently sealed ignitrons. One 200-kw 275-volt equipment and three 300-kw 275-volt equipments have been placed in service at the date of reading this paper.

The principal advantages of the rectifier are, of course, high momentary overload capacity and high efficiency, and these advantages have, in many cases, combined to make the rectifier the most economical conversion unit.

In a typical example of concentrated mechanical mining, a substation is located adjacent to the load center and serves several operating units, each unit consisting of a cutter, a loader, and a locomotive. These machines are powered by intermittent or short-time-rated motors, which have continuous ratings averaging about one-third of the nominal ratings. A substation to serve this group of machines should have sufficient continuous capacity to furnish all the power that the machines can safely absorb on an all-day basis. The substation should also have sufficient momentary capacity to carry over the normal peak load without damage to the conversion unit or interruption of the supply of d-c power. Experience has indicated that this peak frequently approaches the sum of the combined rated currents of all the machines served.

For example, a substation serving six units, having a total of approximately 960 horsepower, should be capable of carrying 900 kw momentarily and 300 kw continuous. Interpreted in terms of conversion units, this means a 300-kw rectifier will operate with fewer outages than a 400-kw rotating machine, since the 300-kw rectifier unit can carry more load momentarily than the 400-kw rotating unit.

At 275 volts, there will be but a minor difference in the cost of the substation including building, foundation, and installation, whether a rotating machine or a rectifier is used, and at 600 volts, the rectifier will definitely be less expensive. Any saving in operating cost obtained by the use of the rectifier will be a net gain.

Basing a power-cost comparison on 275-volt equipment only, the losses of a 300-kw rectifier will average 5 kilowatt-hours per hour less than the losses of a rotary converter over the usual load cycle, and will average 20 kilowatt-hours per hour less than the losses of a synchronous motor generator.

In a mine in which power must be kept on the trolley continuously to operate pumps and other auxiliary services, the annual saving in comparison with a rotary converter will be roughly 40,000 kilowatt-hours, which at a rate of one cent per kilowatt-hour amounts to $400. The comparison with a motor generator shows a saving of 160,000 kilowatt-hours or $1,600 per year.

The savings in 600-volt service are more impressive, since, on the higher voltage, the rectifier efficiency is increased approximately three per cent, while the efficiency of 275- and 600-volt rotating machines are approximately the same.

As of this date, six ignitron rectifiers have each had more than one year of service, the maximum in this group being 32 months and the average 22 months. Nine additional ignitron rectifiers have had less than one year each, the maximum in this group being 9 months and the average 6 months.

In the six equipments of the first group, there are 36 ignitron tanks, 36 excitation thyratrons, 36 ignitor crystals, 6 vacuum pumping systems, and 6 cooling systems. These are the parts which were really on trial in the earlier installations.

No delays have been caused by leaks in the vacuum system and only one shutdown has been caused by any type of failure of the vacuum system. This was caused by improper operation, contrary to instructions. When the mercury was replenished in the mercury-vapor pump and attention was called to the proper method of operation, the trouble was cured permanently.

Four ignitor crystals have been replaced in the field. Two of these were defective crystals which failed very shortly after installation. Two others, which were replaced after approximately one year of service, were not returned to the factory for inspection, so the exact condition of these crystals at the time of reported failure is unknown.

The minimum life of firing tubes has been slightly more than 12 months. Some firing tubes have been in service two years, but the average is at least 15 to 18 months.

Only four of the ignitron tanks have been opened, all for replacement of firing crystals. No other internal parts have been replaced or repaired.

There have been no recent failures of the cooling system. In several of the earlier installations, it was necessary to modify the circulating-water pumps to prevent loss of water and to improve bearings. These modifications have, apparently, eliminated the trouble. Under present conditions, the amount of water required to replenish losses is negligible.

It seems evident, therefore, that ignitron rectifiers, at the present stage of their development, are highly reliable, comparing favorably with rotating machines. The cost of maintenance is extremely low except for the cost of replacing firing tubes, which, judging from existing experience, should average less than $150 per year. In comparison with rotating conversion machines, the over-all cost of maintenance of rectifiers will usually be higher, but the difference should not exceed $100 per year on the smaller ratings. On the larger ratings, maintenance costs will be more nearly equal.

In an analysis of power conditions at a mine, due consideration should be given to the effect of added equipment on the

power factor of the system. A rectifier, with its transformer, operates at an average power factor of approximately 93 per cent. A rotary converter is usually adjusted to operate at unity power factor at the average load, but as an all-day average, will usually operate at something less than unity, lagging. Standard mining motor generator sets are capable of producing a large corrective effect to compensate for inductive equipment on the system. A power-factor analysis can be made only with a full knowledge of local conditions and any further attempt to make a definite statement on this subject would be useless.

As a result of three years' experience in the application and operation of rectifiers in coal-mining service, combined with many years of experience in other industries, we can summarize as follows:

1. Rectifiers are at least equal to other types of conversion equipment in reliability.

2. For equipments of equal service capacity for mining conditions, the installed cost of a rectifier will be approximately equal to or less than the cost of rotating conversion equipment.

3. The operating cost of a rectifier, including maintenance and cost of power, will be less than the operating cost of rotating machines, except where power-factor correction is of considerable importance.

4. Where additional power-factor corrective equipment is necessary, a motor generator, or a rectifier with capacitors may be the preferred type of equipment.

5. An analysis of local conditions, taking into account required service capacity, hours of service per year, power cost rates, and power factor, is necessary to establish which type of conversion equipment is most advantageous.

Discussion

F. L. Kaestle (nonmember; General Electric Company, Schenectady, N. Y.): This paper on "Mercury Arc Rectifiers in the Coal-Mining Industry" is indeed very timely, and is of interest to the entire electrical field, as well as the coal-mining industry.

Mr. Renshaw has very well pointed out that the rapidly expanding mechanization of coal mining has led to an increased interest in rectifiers, because their characteristics are so well adapted to the type of load encountered in this service.

The increased average power load of the mechanized mine has required the installation of more conversion equipment. The fact that the load center is highly concentrated in a relatively small working area, and that this area shifts quite rapidly as the coal is worked out, has increased the need for readily movable underground substation equipment. The development of the ignitron has made it feasible to build portable rectifiers to meet this important shifting-load condition.

The important characteristic of the mine load which makes rectifier equipment particularly adaptable, is that the load fluctuates widely. The cutting and loading machines and the haulage locomotives produce alternately high peaks and light loads during the working shift. Also the trolley usually must be kept energized continuously between shifts, with only the very light load of maintenance and inspection work, and for pumps and lights. The high percentage of very light load periods emphasizes the most outstanding advantage of the rectifier, that of low no-load losses which account for its high efficiency at light loads. As an example, the no-load loss of a 300-kw ignitron rectifier equipment is approximately 4 kw, that of a rotary equipment 12 kw, and of a motor generator 26 kw.

Mr. Renshaw has demonstrated the savings effected by these lower rectifier-equipment losses for a mechanized mine operating 600 shifts per year. This number of working shifts is quite high as an average, and even here the power savings are substantial. For mines working 200 to 300 shifts per year, and there are a large number which do so, the savings are even greater.

High overload capacity must be considered in the design of any equipment for mining conversion, but the means by which it is accomplished are decidedly in favor of the rectifier substation. The continuous rating and hence, to some extent, the physical size of any conversion equipment to carry a high-peak, low-average load can be kept to a minimum if that equipment has a high momentary peak capacity. Even with a rectifier substation, it must be remembered that the rectifier unit itself must still be selected primarily on the basis of the maximum load to be carried. However, the transformers, cooling equipment, and switchgear may be selected primarily on the basis of the continuous rating, and these parts make up a large part of the total equipment. Hence, the high overload capacity can be obtained in the rectifier equipment without the large increase in copper and iron required to obtain it in rotating machines.

One of the principal considerations in the development of the ignitron was to improve the efficiency for application in the 250–275 volt field. In order to reduce the arc drop it was necessary to place each anode immediately above and very close to the cathode. This was accomplished by enclosing each anode with its individual mercury-pool cathode in a separate vacuum tank or tube. These single-anode units are assembled as a group to form a rectifier unit. With such an arrangement, it is necessary for practical design reasons, to initiate the arc each half cycle by means of an igniter, rather than maintain it continuously, as is done in the multianode rectifier. Thus the real operating difference in the two types lies mainly in the ignition systems used, for the basic rectifying principles of the two are the same.

The mechanical construction of the ignitron has served to simplify the rectifier. The low height and light weight of the individual units now make it practical to build portable and underground equipments. The mercury pool does not have to be insulated from the vacuum tank, in the ignitron, and so a sturdier design results. This simplification of the ignitron, together with its improved efficiency, has expanded the use of the rectifier into many new low-voltage fields, including this important coal-mining industry.

Another progressive step, mentioned by Mr. Renshaw, which has permitted the further simplification of the ignitron, is the use of permanently evacuated, sealed tubes. With these tubes, no vacuum-pumping system and no auxiliary equipment to indicate or control vacuum is required. The reliability of the sealed tube, from the standpoint of continuity of service, has been well established by tube equipments for welding machines, synchronous-condenser exciters, and building lighting, as well as by three coal-mining equipments which are now in service.

The lower installed cost of the sealed-tube equipment and the lower maintenance, due to the elimination of vacuum equipment, must be balanced economically against tube renewal costs, and this resolves itself into a question of tube life. Since the tube is constructed of corrosion-resisting materials, its life is dependent on vacuum and ignitor life. Many tubes in welding service have been operating for over four years and are still in service. Although it is too early to know what tube life is in this service, on the basis of very encouraging results so far, it is confidently expected that the tubes will last from three to five years or longer. When their life has been demonstrated, the sealed-tube rectifier will be the most attractive equipment available in ratings of 300 kw and less, where the cost of the pumping equipment is a relatively large item.

Rectifiers have been very successfully applied in 500-volt services for many years and now, with the development of the ignitron, the many operating advantages of the rectifier are available in the 250-volt field. The low light-load losses of the rectifier are its strongest point. The ignitron is simple, sturdy, and reliable. It is easily made portable, and is well suited to underground operation. Rectifier substations are easily provided with high momentary overload capacities. Because of the absence of rotating machines, the rectifier substation equipment is practically immune to damage from lightning.

The sealed-tube ignitron not only retains all the other advantages of the pumped equipment, but also offers a means of reducing the installed cost and maintenance for the ratings to which it is suited.

With the present increase in coal production, the mercury-arc rectifier should play an ever more important role in the reduction of mine operating costs.

D. E. Renshaw: I am very glad to have heard Mr. Kaestle's contribution on this subject, particularly his discussion regarding the permanently sealed ignitrons.

It is quite evident, because of increasing mechanization of mines, additional conversion equipment will be required. It is also undoubtedly true that there are many conversion units still in service which, because of age and long use, are expensive to maintain and are wasteful of power. For this added and replacement conversion equipment, the ignitron rectifier will, in many cases, provide a better source of d-c power at a saving in over-all cost.

New Type of D-C to A-C Vibrator Inverter

O. KILTIE
ASSOCIATE AIEE

VARIOUS SYSTEMS have been devised to operate from direct current to supply alternating current at specified frequencies for specific loads. However, there have been the usual limitations to prevent individual extensive application of each type.

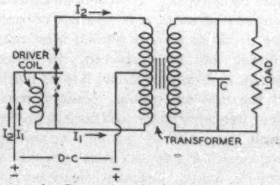
Motor generator and dynamotor type machines do not fill all the requirements for universal needs. Special provisions must be made to obtain good frequency regulation and high efficiency.

Grid-controlled vacuum-tube inverters have been successful for many purposes, but for loads in the lower ranges, the high cost and low efficiency are objectionable. With supply voltages in the order of 6 or 12 volts direct current the normal arc or plate drop of the tube itself may be as much as the supply voltage leaving nothing for the load. Practically instantaneous attainment of rated frequency during the starting period would be an advantage for this type.

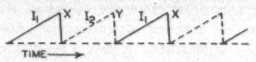
Vibrator-type inverters have been extensively used during the last few years, especially in the automobile-radio field where load requirements have not been severe and long contact life has not been a fundamental requirement. Their use has increased considerably of late for various purposes such as for electric clocks, small motors, musical instruments, and various electrical control equipment.

It is the purpose of this paper to present to the industry a form of vibrator inverter for the conversion of direct current to alternating current, which has been accepted to have many improvements and advantages over other forms and types of inverters including the conventional vibrator system shown in figure 1*A*. It is not the intention in the following paragraphs to criticize the present conventional vibrator system, but merely to establish a basis of comparison for what has been considered to be a distinct improvement.

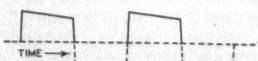
The circuits used for nearly all vibrator applications in the past have been basically similar to the circuit of figure



A—Conventional vibrator circuit



B—Contact current in circuit of *A*



C—Output voltage from circuit of *A*

Figure 1

1*A*. Modifications are found in various methods for starting and driving the vibrating reed. By referring to figure 1*B* it is evident that during the "closed" period of each cycle the line current comprised of I_1 and I_2 continues to increase until the circuit is opened at points *X* and *Y* by the vibrator contacts. Alternate current impulses occur for respective paths of the battery circuit as shown. The general wave shape of the output voltage is acceptable for many applications, however, the fact that the contacts are compelled to break an increasing current at a maximum value proves disastrous for appreciable load currents. The resulting spark produces considerable heat and transfer of contact materials. Extremely high frequency components occur at the "make" and "break" from the resulting spark, to cause objectionable radio disturbance. Suppressors must always be added to avoid such interference. If for any reason, action of the vibratory reed should stop while either set of contacts is closed, the battery or supply-line current would increase to high values only limited by the d-c resistance of the circuit and the protective device, if used. Adequate capacitors are required and are connected either across the output load or across each set of vibrator contacts with correct associated resistance to decrease sparking to a minimum.

New Type Vibrator Circuit

A vibrator-type inverter satisfies the requirements for simplicity, low cost, high efficiency, and very few moving parts. Its serious enemy, as described previously, is the damaging spark during the opening of the contacts. Frequency regulation is excellent. Small size is a desirable feature. To develop a new inverter the decision was made in favor of the vibrator type with the fundamental objective being to reduce the circuit current to zero before allowing the vibrator contacts to open. It was apparent if such a condition could be made possible, the contact life should be very long and result in a most reliable type of inverter. Such was the process of development and the following paragraphs explain the theory followed.

If a reactor *L*, capacitor *C*, and resistor *R*, be connected in series across a source of direct voltage through a switch as shown by the solid lines of figure 2*A*, an approximate sine-wave half-cycle current can be obtained. The extent of continued oscillation will depend upon the damping of the circuit resistance *R*. Assuming the capacitor to be completely discharged when switch 1 is closed, the current will increase to a maximum and reduce to zero as the capacitor becomes fully charged. If switch 1 is opened at point *X* in the current wave I_3 of figure 2*B*, there will be no spark at the switch since the current at that moment is zero and the capacitor will be charged to a potential equal to line voltage. When closing switch 2, capacitor *C* will begin to discharge and force a current I_4 to duplicate the charging current I_3 in all respects except that it will flow in the reverse direction. Again no spark will occur at switch 2 if it is opened at point *Y*. The capacitor and reactor have definite reactance constants, therefore currents I_3 and I_4 individually acquire the same definite resonant frequency. Amplitude of the two waves will be equal providing the

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The author gratefully acknowledges the assistance of M. A. Edwards, B. D. Bedford, and H. W. Lord of the General Electric Company, Schenectady, N. Y., for their valuable contributions toward this development especially with regard to train lighting, and the work of R. A. Oberlin, General Electric Company, Fort Wayne, Ind., for conducting much of the development testing.

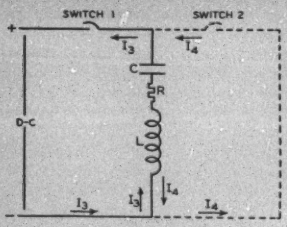

Figure 2A. Circuit to obtain one cycle of charge and discharge alternating current

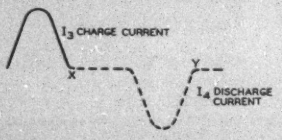

Figure 2B. Charge and discharge current waves

resistances of the two paths are equal Alternating current can thus be obtained if the switching operations occur alternately and uniformly. For switching purposes the conventional type vibrator may be substituted most ideally if the respective contacts be made to open the circuit corresponding to the points X and Y in the current waves of figure 2B. Resistance R represents the load which should be of the proper value to obtain correct damping of the load current. By omitting the reactor the current will increase at a very rapid rate equivalent to a high frequency and the current will decrease, in that same half cycle, at a very slow rate which would be equivalent to a low frequency, so that wave shapes of this type would be of little value for power purposes. A new inverter circuit as shown in figure 3 is thus made possible. The circuit is similar to the charge-discharge circuit of figure 2A except that the output transformer has been added to couple the load resistance with the exciting source. Certain type loads may be supplied directly from a single low-reactance transformer excluding the use of a tuning reactor L. Such is possible only where a lagging-power-factor load provides the necessary inductive reactance to reflect in series with the capacitor C to provide the correct resonant frequency. In other applications as described later, for neon-tube purposes, the tuning reactance may be combined in a single output transformer by providing sufficient leakage reactance between the two windings. General applications usually require the inductance be provided as a separate unit and that the output transformer be of the conventional low-reactance type with minimum leakage reactance between windings.

Since the load current can be made to reduce to zero, an ideal time in the cycle is available immediately after each half cycle for the contacts to open the circuit to switch for the alternate half cycle. During the moment of no current flow the contacts may be opened with absolutely no spark or damage whatsoever, and the primary objective of the development has been achieved.

It is essential to choose circuit constants such that the load current will increase to a maximum and decrease to zero during a single closed period of one pair of contacts. To obtain maximum output load watts, it is desirable to open the circuit as soon as possible after zero current has been reached. In other words, load current should flow as much of the time as possible. Uniform resonant frequency of the load current can be easily controlled by holding the reactor and capacitor reactance constants within definite limits. Constant frequency of the vibrator is made available at little extra expense, since the vibratory reed has that inherent characteristic. Since many applications require a specific frequency the frequency of the vibrator must be chosen to agree. The resonant frequency of the load current must then be designed to a value approximately ten per cent higher in order that the contact current is at zero before the contacts open. Absence of current at opening of contacts makes it impossible for destructive sparking to occur. The contacts are required to withstand only mechanical wear and resistance heating.

Line current from the d-c supply consists of charging current only, so the effect is a series of d-c pulsations in exactly the same shape and amplitude as the positive half cycles of the alternating current in the oscillogram of figure 4A. Since line current from the battery flows only half the time, a d-c ammeter measurement will be slightly less than half the a-c measurement of current in the capacitor leg.

Perhaps the features and advantages of the new inverter are best proved and most evident by referring to the oscillogram of figure 4A, which shows the alternating current I_3 of circuit per figure 3. It consists of both the charge and discharge half-cycle currents in alternate arrangement. The oscillograms of figures 4A, 4B, and 4C were taken with an inverter connected according to figure 3 and connected to a 96-per-cent lagging-power-factor load. The following test data will show actual relative measurements and are true for the conditions of the various oscillograms.

E_1—Line volts, direct current.....110
I_1—D-c line current.....1.4 amperes
E_2—Load volts, alternating current.....107 (figure 4B)
I_3—Load current, alternating.....1.18 amperes
Load watts.....122
I_5—Capacitor current.....3.68 amperes (figure 4A)
Capacitor C.....124 microfarads
Reactor L.....0.0241 henry

Phase relation and comparison may be made of a-c output volts E_2 with capacitor current I_5 by referring to figure 4C. It is apparent that wave shapes are quite satisfactory for most purposes. From close inspection of the oscillograms it can be seen exactly where the vibrator contacts close and open.

There are various methods to start the vibrator in motion, the most simple of which is to connect the driver coil of the vibrator directly across the load contacts on the battery side as shown in figure 3. When closing the d-c supply switch an initial current will flow through transformer primary, capacitor, and driver coil. Even though this current is small it establishes a directional flux to start operation of the vibratory reed in the usual manner. During the initial swing of the reed the corresponding contacts close and allow for the first half cycle of charging component of the load current. Simultaneously, the driver coil becomes short-circuited to remove the magnetic pull upon the reed, which allows the reed to swing back across the center position to close the other pair of vibrator

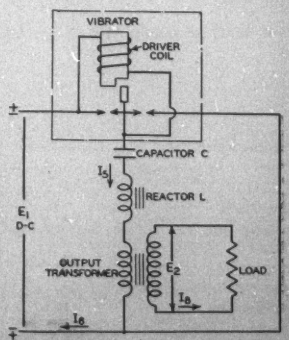

Figure 3. New type of d-c to a-c vibrator inverter

contacts. During this period the discharge half cycle occurs. Since the short circuit has been removed from the driver coil, the reed is again pulled in the opposite direction to repeat the continuous cycle. The natural frequency of the reed determines the a-c frequency.

This development has created new requirements for capacitors. The volt-ampere output depends directly upon the value of capacity, so for appreciable loads from low direct voltages especially, the number of microfarads reaches a large figure. The a-c electrolytic type capacitor has proved most suitable for such requirements, chiefly because of its small size and low cost. Power factor and losses should be low. Inductive effects in the capacitor and in the lead connections between the terminals and foil create a surge impedance which may reject a capacitor satisfactory in other respects.

The a-c output can be synchronized with an isolated a-c power source by providing the driver coil of the vibrator with a suitable low voltage obtained directly from the synchronized voltage.

An important feature is that which allows the d-c supply current to reduce to zero if the vibratory reed should stop in any position of its normal operating range while the d-c line switch remains closed. Since the capacitor becomes charged and remains charged, no current can flow. The battery or d-c circuit is opened if the discharge contacts remain closed.

From this development it appears the new inverter will be ideal for many specific applications. At the present time much hope is held for it to enable the use of standard 110-volt a-c television receivers in d-c districts, its chief advantage being in constant frequency and lack of disturbing interference. Radio receivers on police cars are required to operate almost continuously. The plate-supply direct voltage can be supplied from a vibrator of this type with considerable assurance of reliable operation.

Application for Neon Signs

The original purpose of this development was to find a new cheap method to supply suitable high voltage for neon signs on automotive vehicles. For such purposes the inverter must operate on any condition from short-circuit to open-circuit loads. A circuit the same as figure 3 may be used except that the output transformer requires sufficient leakage reactance between windings to hold the tuning reactance within reasonably close limits to prevent contact sparking for the various load conditions. An inverter suitable for most neon sign applications for 6.0-volt d-c service supplies 7,500 volts open circuit which is suitable for ten feet of nine-millimeter-diameter red neon tubing. Battery drain is almost constant at 3.5 amperes for any load condition. An electrolytic capacitor of 6,500 microfarads is necessary for this purpose. Wave shapes are so favorable that smoothness and appearance of the tubing while operating is comparable with that from any commercial a-c supply.

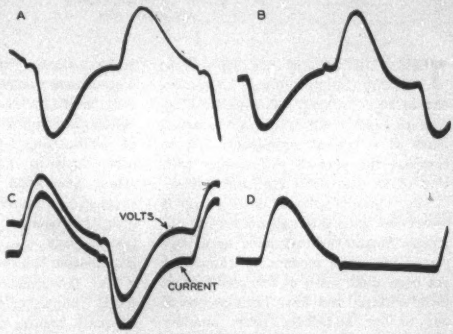

Figure 4. Oscillograms of inverter current and voltage of figure 3

A—Alternating current I_3

B—Output alternating voltage E_3

C—Relation of current I_4 and output voltage E_3

D—D-c line current I_4

Application to Fluorescent Mazda Lighting on Railway Cars

The problem of supplying suitable a-c power to a group of the new fluorescent Mazda lamps from 32- or 64-volt batteries seems to be very well satisfied by this type of inverter. An efficiency of 75 per cent is maintained throughout the normal variation of the battery voltage. Best operation is obtained with a load power factor near unity although variations, either leading or lagging, may be tolerated.

Several railway cars[1,2] have now been equipped with fluorescent lights and vibrator inverters of this type.[3] With no changes necessary to the batteries and generators of existing equipment in service, it is possible to increase the average illumination on the reading level from approximately three foot-candles with tungsten lamps to approximately eleven foot-candles with fluorescent lamps. The losses of the inverter and lamp ballast auxiliaries have been considered in this comparison.

The constant frequency of the inverter power supply becomes a valuable feature since the lamp auxiliary is of the reactance type. Even with battery voltage variations from 28 to 43 volts the vibrator has been made to hold almost constant amplitude of the vibratory reed and to provide almost a constant frequency of 60 cycles. Therefore, with a constant frequency of the power supply the voltage may be allowed to vary to some extent without causing damage to the auxiliaries or to the fluorescent lamps. It then makes it possible to eliminate the lamp regulator which has been necessary for tungsten lamps on railway cars.

Present rated outputs from 32-volt sources have not yet much exceeded 250 watts, so for loads of 1,000 and 1,500 watts, panels of four sections and six sections respectively are used. Each 250-watt section is connected to a group of from 12 to 16 lamps as required. Progress of development for the actual installations in service has been conservative on the safe side. It is evident that the present output can be increased, although it is believed that standardization of ratings may establish the 250-watt size as close to the preferred rating.

This entire development is so new and recent that further research and development will naturally bring many improvements.

References

1. *Railway Electrical Engineer*, March 1939, page 41.

2. *Railway Electrical Engineer*, October 1938, page 212.

3. *General Electric Review*, January 1939, page 32.

Discussion

B. D. Bedford (General Electric Company, Schenectady, N. Y.): Mr. Kiltie's paper is of great value in that it introduces a vibrating-switch inverter employing an

Variable-Voltage Equipment for Rotary Drilling Rigs

E. H. LAMBERGER
ASSOCIATE AIEE

THE PURPOSE of this paper is to tell why variable-voltage equipment should be considered for oil-well drilling rigs, to explain the operating characteristics of a typical equipment, and to compare the over-all performance with that of an equivalent mechanical drive.

The variable-voltage drilling rig is associated with internal-combustion engines. Steam turbines have been suggested for prime movers, but have not yet been used. A-c motors can be used to advantage, and have been proposed, but to our knowledge never actually used.

Let us review briefly some of the disadvantages of steam equipment as compared to the internal-combustion engine. A safe and adequate water supply for steam boilers is sometimes difficult and expensive to obtain. The water supply for cooling internal-combustion engines is, comparatively, a small amount. Steam boilers are bulky and heavy units. There are usually not less than three per rig, each weighing approximately 30,000 pounds or as much as the two large-capacity Diesel engines used on a comparable heavy-duty mechanical drilling rig. The boilers are also much bulkier than the engines. Inspection and maintenance is a more serious item with boilers than with internal combustion engines. Steam offers the possibility of boiler explosion which represents a hazard to life and property. The open fire under the boiler presents a real hazard in case of a gassing well. When gas is not available, as in the case of "wildcatting," the transportation of other fuels in quantities required for steam generation entails considerable expense. Assuming liquid fuel, the quantity required for internal combustion engines will be considerably less than that for boilers.

The development of reliable high-speed internal-combustion engines of adequate rating, brought a real competitor of steam as a source of power for drilling oil wells. While steam rigs still predominate by a wide margin, the internal-combustion-engine drive is being used in increasing numbers. Improvements in steam equipment such as the use of higher steam pressures (500 to 800 pounds per square inch) and superheat, will undoubtedly be matched by improvements in internal-combustion-engine equipments such as the development of larger-capacity and higher-speed engines. Variable-voltage transmission with its many advantages will help in further increasing the use of the internal combustion engine.

Difficulties Encountered With a Mechanical Transmission

As the internal-combustion engine cannot pick up any appreciable load from standstill, a clutch must be provided. This clutch must slip while the load is being accelerated to a speed corresponding to the engine speed, and at the same time transmit a torque as required by the load. This means clutch wear. The manipulation of the clutch results in engine stalling or near stalling, sudden changes in engine speed, and shock loads on the engine and mechanical transmission. Such factors mean high maintenance of the engines and of the entire mechanical transmission. Also, it is practically impossible to pick up a heavy load with the smoothness desirable when doing a fishing job. The mechanical transmission is inflexible as to arrangement because the engines must be close to the draw works and the mud pump.

What Is Meant by a Variable-Voltage Equipment

Before considering the advantages of a variable-voltage drilling equipment let us outline briefly what such an equipment consists of. Such an equipment consists of d-c generators a portion of whose fields are supplied by separate excitation, and whose voltages are varied and reversed by controlling their fields; motors with shunt fields separately excited, so their direction of rotation and speed are changed as the polarity and value of the generator terminal voltages are changed; constant voltage exciters to provide for separate excitation of generators and motors, and a source of auxiliary power;

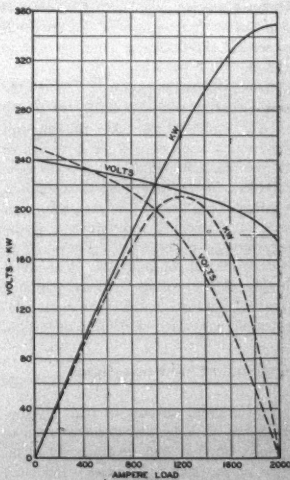

Figure 1. Generator characteristics

Solid curves—With separately excited and self-excited shunt fields

Dashed curves—With separately excited and self-excited shunt fields and also series differential field

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improved method of commutation. This improvement makes this type inverter capable of handling much larger loads, with reduced contact wear. The new design greatly expands the number of applications in which vibrating-switch inverters may be used.

Practically all small independent electric power systems, such as those found on automobiles, railway cars, airplanes, small boats, and isolated farms, obtain continuity of service by storing electric energy in batteries. At present, the manufacturer must design and the consumer must buy many special lamps, motors, and other appliances for operation on these low-voltage d-c circuits. The vibrating-switch inverter will have an important place in the electrical field, for it is now practical to convert the battery energy of these independent systems to alternating-current so that standard a-c apparatus may be used.

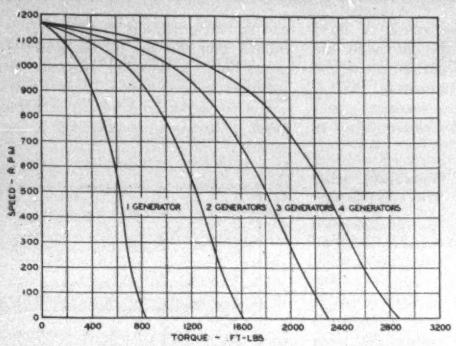


Figure 3 (left). Motor speed-torque characteristic with generators in parallel

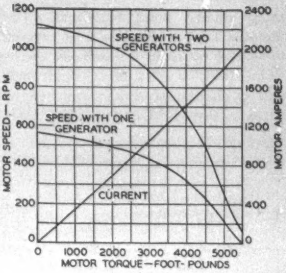


Figure 4 (right). Motor speed-torque characteristic with generators in series

a control equipment which gives full control of power application to all main motors for drilling or hoisting operations from the driller's position.

The generators as here used are more than simply variable-voltage machines. In addition, they have a shape of voltage curve which droops to zero at some predetermined current value. Such a curve establishes two desirable limits:

1. The peak generator output and consequently the peak demand on the engine can be limited to the maximum desirable output of the engine. Once established the protection to the engine is automatic, regardless of pump, table, or hook load. The electric motors can even be stalled without danger of stalling or even slowing down the engines.

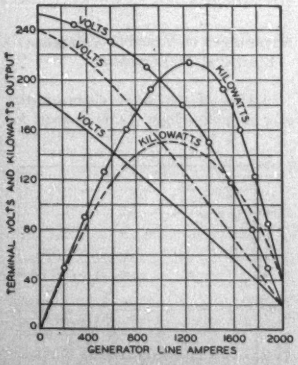


Figure 2. Generator voltage and kilowatt characteristics

Circles—Three-field generator with series differential field

Solid curve—Three-field generator with self-excitation eliminated

Dashed curves—Two-field generator with series differential field

2. The maximum current that can be circulated when a motor is stalled can be limited to that value which is considered a safe maximum from the standpoint of both the mechanical and electrical equipment. Such a limitation is particularly desirable for mud-pump and table drives.

How these generator characteristics are obtained will be discussed in detail later in this paper.

Separate shunt excitation of the motors provides two principal advantages. (1) The motors are reversed as the applied armature voltage is reversed. Motor reversing is therefore accomplished by means of only small generator-field-circuit contactors. With series or compound fields, large main-circuit contactors would be required. (2) The use of a separately excited field assures that the torque exerted by the motor will be always proportional to the armature current. This is important where high momentary torques are required, as when pulling on a stuck pipe.

The exciters, or auxiliary generators, are constant-voltage machines. They are suitable as exciters for the fields of the generators and motors, and as a source of auxiliary power for lighting, shale-shaker motor, raw-water motor, engine-cooling-tower circulating-pump motor, and any other auxiliary load.

The control is relatively simple. Since motor speed control and motor reversing are accomplished by the manipulation of only small generator field currents, the necessary circuits can be handled directly on a drum controller. It is therefore easy and economical to provide a large number of speed points. Means are provided for transferring available generator capacity to any motor circuit in case of emergency. Derrick-floor control units, such as the master controllers, drill-hoist selector switch, and emergency stop push button, are of the oil-immersed or explosion-proof type. Master controllers provide for 20 points of speed control and are operated from the driller's position.

Generator Characteristics

Let us consider how the generator characteristics referred to above are obtained.

Figure 1 illustrates the voltage and kilowatt characteristics of a generator equipped with only shunt fields, including both self- and separate excitation, and the same generator equipped with self- and separately excited shunt fields and also differential series fields. It is apparent that the machine with only shunt fields has a power demand characteristic which would be unsuited to internal-combustion-engine drive on a drilling rig. The demand on the engine with such a generator characteristic increases approximately in proportion to the current or motor torque required. It would require careful attention of the operator to avoid overloading and stalling of the engine. Such close attention is not desirable.

The curves for the generator arranged with shunt fields and differential series fields indicate that the maximum demand on the engine can be limited. The demand on the engine actually decreases as the armature current increases beyond that value corresponding to the peak generator kilowatts. This means that the engine is actually working more easily when excessive motor torque or hook pull is being exerted than when normal torque or pull is required.

Either of these generators could be of the variable-voltage type. In the first case the operator must give attention to engine loading, while in the other case the engine is automatically protected against overloading.

A drooping generator characteristic can be obtained by using only a sepa-

rately excited shunt field and a differential field, referred to as a two-field design, or by using a separately excited shunt field, a self-excited shunt field, and a differential series field, referred to as a three-field design. The three-field design has the advantages that for a given frame size a higher no-load voltage, a greater continuous kilowatt rating, and a greater peak kilowatt output are obtainable than are possible with a two-field design. These results are due to the following reasons.

In either case, at the maximum desired armature current the differential series field must be approximately equal in strength to the separately excited shunt field. If the shunt excitation is made up entirely of separate excitation, the series field will occupy a greater percentage of the field space than it would if the separate excitation were only one-half of the total shunt excitation. Therefore the space for shunt, or positive excitation is less in the two-field generator than in the three-field machine. Also the self-excited shunt field provides an automatic increase in excitation with increased voltage, within the limits of the saturation curve of the machine.

Figure 2 illustrates typical voltage and kilowatt output characteristics of the two different field windings on a given frame size of generator. The no-load voltage of the two-field generator is 241 volts compared to 253 volts for the three-field machine. The voltage of the two-field machine drops quite rapidly with increase of load from no load, while it is relatively well sustained in case of the three-field design. This means higher operating speeds for light loads. Assuming that each machine is to rate 1,000 amperes, it will be noted that the voltages at this current for the two- and three-field generators are 150 volts and 200 volts respectively. Therefore the rating of these machines would be 150 kw and 200 kw respectively. It will be noted further that the peak output of the two-field machine is very little greater than the rated value, while the three-field machine gives a peak output seven per cent higher than its rating. Therefore, the assumed frame with three fields can transmit a peak engine horsepower corresponding to a generator output of 214 kw, while the two-field machine can transmit an engine horsepower corresponding to a peak generator output of only 152 kw.

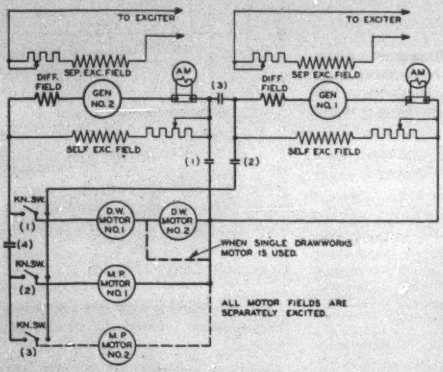


Figure 5 (left). Schematic wiring diagram

Two generators arranged for series operation during hoisting

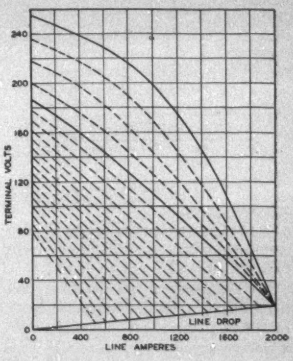


Figure 6 (right). Voltage characteristic of typical 200-kw generator illustrating voltage curves to give 20 points of motor speed control

Types of Equipment

The equipment may be "full electric" or "semielectric." With a full-electric equipment the draw works, table, and mud pump are all driven electrically. The table may be driven by the draw-works motor through the draw works, or by a separate table motor. With a semielectric equipment the mud pump is driven mechanically.

Generators may be connected in series or in parallel. Figure 3 illustrates the speed-torque characteristics of a motor operating on one, two, three, or four generators in parallel. It is evident that the loss of a generator reduces almost proportionately the motor torque available. This is a disadvantage of this system. Paralleled generators have the advantage however that standard-voltage machines may be used, regardless of the number.

Figure 4 illustrates the speed-torque characteristic of a motor operating on one or two generators in series. It is evident that the loss of one generator means only a negligible reduction in maximum motor torque. There is however a proportionate reduction in motor speed. There is a practical limit to the number of generators which can be used in series. From the standpoint of safety and from the standpoint of standard industrial insulation limits the maximum generator voltage should not exceed 600 or possibly 750 volts. It is evident then that if a large number of generators are used the voltage rating will be low with consequently high ampere rating. In extreme cases this results in expensive generators.

Advantages of Variable-Voltage Electrical Transmission

In view of the above characteristics of a variable-voltage d-c equipment for

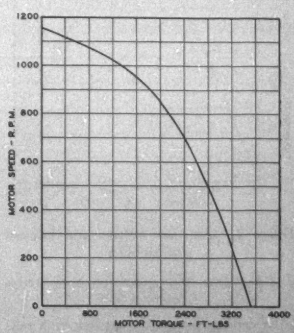


Figure 7. Speed-torque characteristics of 300-horsepower mud-pump motor operating on 250-kw generator

Table I. Data on Weights, Speed Ratios, Mechanical Efficiencies, and Times Allowed for Making and Breaking Joints

Maximum depth of hole (feet)	6,480
Weight of traveling block, hook, and elevators (pounds)	15,000
Weight of 6,300 feet of 6⅝-inch 31.9-pounds-per-foot drill pipe (pounds)	200,000
Weight of reamers, drill collars, and bit (pounds)	15,000
Total effective weight of string (pounds)	230,000
Number of lines used	6 or 8*
Governed engine speed—either drive (rpm)	600
Speed ratios—electric drive:	
Drilling gear—internal	3.2:1
Drilling gear output shaft to draw-works jack shaft	1:1
Over-all—motor shaft to draw-works drum shaft:	
High-high	2.85:1
Low-high	4.74:1
High-low	10.50:1
Low-low	17.50:1
Speed ratios—mechanical drive:	
Engine through reverse gear to draw-works jack shaft	2.8:1
Over-all—engine to draw-works drum shaft:	
High-high	2.49:1
Low-high	4.14:1
High-low	9.18:1
Low-high	15.3:1
Mechanical efficiencies (per cent):	
Electric drive:	
From engine flywheel to generator pulley	95
From draw-works motor shaft to hook	74
Mechanical drive:	
From engine flywheel to reverse gear	92.7
Through reverse gear to hook	73.3
Over-all efficiencies from engine flywheel to hook, at maximum output:	
Electric drive	56.8
Mechanical drive	67.8
Effective drum diameter—second layer 1⅛-inch line (inches)	29
Coming out, either drive, six or eight lines: Seconds allowed to break joint, set stand aside, and drop hook (per stand)	35
Going in, either drive, six or eight lines: Seconds allowed to pick up stand, make joint, and drop string (per stand)	50

* Assume buoyancy counteracted by friction during hoisting.

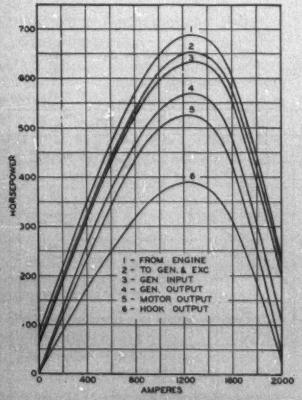


Figure 8. Power absorption between engines and hook with electric transmission

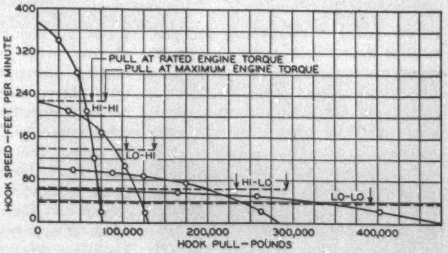
oil-well drilling, let us consider the advantages offered by this type of power transmission as compared to a mechanical transmission.

1. Engine-clutch manipulation in connection with load pickup is eliminated. The clutches are used only when starting up the generator set, therefore delays and expense due to clutch maintenance are negligible. Shocks to engine and mechanical equipment incident to clutch manipulation when picking up loads are eliminated, and consequently maintenance of mechanical equipment and delays caused thereby are reduced.

Figure 9. Hook speed versus hook pulls for various draw-works combinations using eight lines

Solid curves—Electrical drive

Dashed curves—Mechanical drive



2. The engine cannot be overloaded or stalled. This eliminates delays in operation. The engine operates at constant speed regardless of load, a condition much easier on the engine than when speeds are varied widely and suddenly.

3. Loads are picked up smoothly. The inherent characteristics of the electrical equipment, including the control, prevent shock loads on the engine or the mechanical equipment.

4. A wide range of motor speeds and torques is available. Voltages at light loads, and consequently operating speeds with such loads, are 15 to 25 per cent above rated speeds; full-load torques may be handled at many speeds ranging from zero to full speed; torques ranging from 40 per cent to 200 per cent of full-load torque may be exerted at zero speed; the maximum torque to be exerted at zero speed can be predetermined.

5. Operating records are easily obtained. Engine performance may be checked by measuring generator output; energy consumption for various operations may be determined; charts showing changes in operating conditions may be obtained.

6. Equipment may be located to best advantage. The power plant and mud pit may be placed at any convenient location.

7. Flexibility as to prime movers and total rig capacity are provided. Engines of the Diesel, gas, or gasoline type or a-c motors may be used as prime movers; one or a few large engines, or many small engines may be used; two separate equipments may be used on one rig to double the power available.

8. Loss of an engine does not reduce the maximum hook pull available when generators are connected in series.

A Typical Equipment

A typical full-electric equipment with two generators arranged for operating in series during hoisting would consist of the following apparatus:

1. One complete generator unit consisting of the following:

(*a*). One 250-kw 200-volt 1,200-rpm generator

(*b*). One 200-kw 200-volt 1,200-rpm generator

(*c*). Two 20-kw 115-volt 1,200-rpm exciters

(*d*). Equipment assembled and wired on rigid skid-type bedplate

2. One 200/400-horsepower 200/400-volt 450/900-rpm draw-works motor

3. One 300-horsepower 200-volt 900-rpm mud-pump motor

4. One 200-horsepower 200-volt 900-rpm auxiliary mud-pump motor

Note: All ratings are continuous based on 40 degrees centigrade rise. This allows for overloads and high ambient temperatures encountered in drilling oil wells. Forced ventilation of motors is used so that (1) motor ventilation will not vary with motor speed, thus assuring full ventilation with overloads, and (2) to make it possible to provide safe air to the motor in case of gaseous atmosphere.

5. One complete variable-voltage control equipment which would include the following items:

(*a*). One main control cabinet containing contactors, relays, knife switches, exciter meters and rheostats, etc.

(*b*). One derrick-floor resistor rack, containing generator field resistors, and with two 20-point reversing oil-immersed master controllers mounted thereon

(*c*). One draw-works post control mechanism, with two wheels arranged so that generators may be controlled independently during drilling, or simultaneously during hoisting

(*d*). One oil-immersed selector switch by means of which the circuits are set up for drilling or for hoisting

(*e*). One explosion-proof emergency stop push button

(*f*). One weatherproof meter cabinet with an ammeter for each generator circuit

Typical Main Circuit Diagram

Figure 5 shows a typical main circuit diagram for a two-generator full-electric equipment arranged for inde-

pendent use of generators during drilling and series-connected generators during hoisting.

Performance of Typical Equipment

During drilling the 200-kw generator supplies power to the draw-works motor for table drive, or to the separate table motor if used. The 250-kw generator supplies power to the 300-horsepower mud-pump motor. The voltage characteristic of the 250-kw generator is similar to that shown by figure 6 for the 200-kw generator except that for this machine the curve drops to 20 volts at approximately 2,500 amperes, and produces rated voltage at 1,250 amperes. This figure also illustrates the speed control provided by the 20-point controllers. The speed-torque curve of the mud-pump motor operating on the 250-kw generator is illustrated by figure 7. It may be pointed out here that the engine capacity need not be sufficient to carry a total generator output of 450 kw. Let us assume two 350-horsepower engines are used. The two engines drive the generator set and are connected by a coupling between the generators. They therefore divide their output between the generators as required. During drilling the power demand for table drive is usually considerably less than 200 kw, and therefore adequate engine capacity is delivered to the 250-kw generator so the mud-pump motor can operate at full capacity.

During hoisting the characteristic of the 250-kw generator is automatically changed to match that of the 200-kw generator, so that the combined total rated output of the two generators is 400 kw. The 400-horsepower draw-works motor takes the full output of the two generators during hoisting. While the motor is overloaded at times, this is permissible as this motor was previously only partially loaded and because the effective value of the load may still be within a safe value from the standpoint of final motor temperature since the hoisting job is done in a relatively short time.

Transmission Efficiencies

Figure 8 illustrates distribution of engine power during hoisting, from the engine flywheel to the hook, exclusive of that power required for auxiliary circuits. Curve 1 of this figure illustrates the maximum demand which can be made upon the engine for any indicated ampere load on the two generators in series. The maximum possible demand is 687 horsepower, which would be the required output of the two engines combined. This peak power demand occurs at approximately 1,300 amperes. The power demand decreases for current values greater or less than this value. It is therefore evident that as the demand for hook pull becomes excessive, the load on the engine actually decreases, thereby eliminating any possibility of stalling the engine.

The difference between curves 1 and 2 represents the power absorbed in the mechanical transmission between the engine and the generator set pulleys. The difference between curves 2 and 3 represents the power required for electrical excitation and control, and for the necessary motor blowers. The difference between curves 3 and 4 represents the losses in the generators, and the difference between curves 4 and 5 represents the losses in the cable and the draw-works motor.

Curve 5 indicates the power available at the motor shaft, with a peak value of 526 horsepower corresponding to the 687-horsepower engine output value. This represents a transmission efficiency from engine flywheel to motor shaft of 76.8 per cent. Curve 6 indicates the power available at the hook. With 687 horsepower demanded from the engine, the output at the hook is 390 horsepower. The over-all efficiency from engine to hook is therefore 56.8 per cent.

Similar calculations for the mechanical transmission result in an output at the hook of 466 horsepower, with an engine output of 687 horsepower. This

Figure 12. Time for coming out of and going into 4,680-foot hole using six lines

Solid curves—Electrical drive

Dashed curves—Mechanical drive

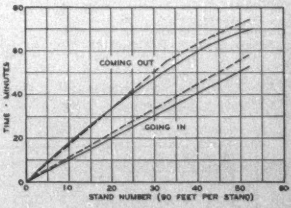


Figure 10. Hook speed versus hook pulls for various draw-works combinations using six lines

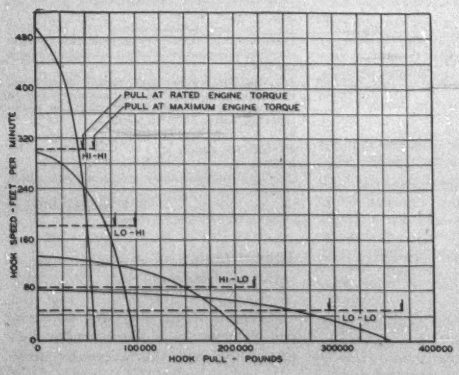
Solid curves—Electrical drive

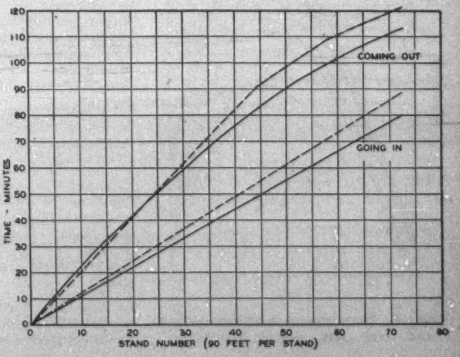
Dashed curves—Mechanical drive

Figure 11 (below). Time for coming out of and going into 6,480-foot hole using eight lines

Solid curves—Electrical drive

Dashed curves—Mechanical drive





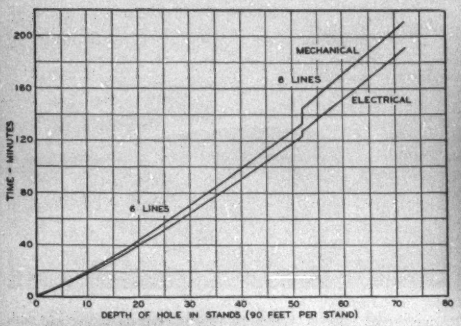


Figure 13. Time required for making round trip for any depth hole up to 6,480 feet, 72 stands, using six lines to 52 stands, eight lines 53 to 72 stands

Identical engines used with both drives

Figure 14. A 200-horsepower mud-pump motor

Figure 15. A 400-horsepower draw-works motor

Figure 16. A 75-horsepower mill-type table motor

represents an over-all efficiency of 67.8 per cent for the mechanical transmission as compared to 56.8 per cent for the electric. The efficiencies used for the various mechanical portions of the drives between the engine and the hook are given in table I.

Comparative Performance When Hoisting

Figure 9 illustrates the motor characteristics with two generators, of figure 4 converted into hook pull and hook speed, with a four-speed draw works and with eight lines on the blocks. Figure 10 illustrates the same characteristics with six lines on the blocks. Table I gives the data used for these conversions.

Figures 9 and 10 also show the hook pull-speed characteristics possible with the same engines but with mechanical transmission. The same draw-works unit is used for both drives.

The rated horsepower available to either drive is 650 horsepower. It is assumed that the engines have a maximum overload capacity of 25 per cent. The electric drive uses some of this margin when developing its peak output when hoisting, while the mechanical drive uses a corresponding portion when accelerating loads at the time draw-works combinations are changed. It will be noted that the maximum hook pull available for each draw-works speed combination is approximately the same for both drives. The equipments are therefore on a comparable basis from the standpoint of over-all speed ratios and use of engine power.

For each draw-works combination the hook speed with electric transmission becomes considerably higher than is possible with the mechanical transmission. This is because the electric motors increase in speed as the load decreases. No such increase in speed is possible with mechanical transmission because the engine is held to a definite maximum desirable speed by the governor. At heavy pulls the hook speed with mechanical transmission is higher than with the electric transmission. It should be noted, however, that the increase in hook speed with reduction in hook load is relatively rapid with the electric transmission. It may also be observed from these curves that the electric drive follows more closely the curve of constant horsepower than does the mechanical transmission.

An attempt has been made to calculate the hoisting performance of each of these equipments. The depth of hole, the weight of equipment, and other pertinent data on which these calculations were based are given in table I.

Figure 11 shows the time required for coming out and going into a 6,480-foot hole, for both equipments with eight lines on the blocks. The curves for coming out illustrate the higher speed of the mechanical equipment at very heavy loads, and the higher speeds of the electric drive at lighter loads. Thus, at about the 24th stand the accumulated time for the mechanical rig becomes greater than for the electric rig. When going into the hole the time is always less with the electric drive. This is due to the higher free-hook speed with this drive.

The total saving in round trip time with the electric rig as indicated by figure 11 is approximately 18 minutes. This is a saving of 8.6 per cent of the time required with the mechanical transmission, which is approximately 210 minutes.

Figure 12 shows comparative performance of the two transmissions with six lines on the blocks when coming out of and going into a hole 4,680 feet (52 stands) deep. The saving in time per round trip with the electric transmission

Figure 17. Semielectric-rig power unit

Figure 18. Full-electric-rig power unit with belted generators

is 9.5 minutes or seven per cent of the 132 minutes required with the mechanical drive.

Figure 13 shows the time required to make a round trip to any indicated depth for each type of transmission. It is assumed six lines will be used until a depth of 52 stands is reached after which eight lines will be used. From this curve can be calculated the total comparative time for making all round trips during the drilling of a well. If we assume an average bit life of 90 feet of hole, after drilling to 450 feet, the number of round trips to drill to 6,480 feet would be 66. The time for making each round trip to renew the bit can be taken from figure 13.

The total time required with a mechanical transmission would be 114 hours, as compared to 103 hours with the electric drive. This means a total saving of 11 hours or 9.6 per cent with the electric transmission as compared to the mechanical transmission.

This saving in time takes into account only the comparative speed-pull characteristics of the equipments and does not include savings in time that are realized with the electric transmission as a result of easier and more flexible control manipulation by the operator, elimination of delays incident to overloading or stalling the engine, and eliminating of delays incident to failure or maintenance of the mechanical transmission as a result of shock loads occuring therewith. The savings shown are obtained in spite of the lower overall efficiency of the electric drive. They are due to the higher speeds at light loads and to the inherent characteristic of the electric transmission which more closely follows the curve of constant horsepower.

Summary

Compared to a mechanical drive, the d-c variable-voltage transmission has several important advantages. These are:

1. Loads may be picked up smoothly and handled smoothly over a wide range of controlled speeds.

Figure 19 (above). Power unit with two cross-connected direct-connected generators

Figure 20. Four close-coupled engine-generator sets mounted on trailer

Figure 21 (below). Twelve-generator power plant made up of two six-generator equipments

2. Flexibility as to: location of equipment; number, type, and capacity of prime movers; and combining of two equipments.

3. Lower maintenance of power plant and transmission due to elimination of abuses incident to clutch manipulation.

4. More continuous drilling due to elimination of delays incident to clutch manipulation, to inherent operating characteristics, and to less time out for repairs.

In view of such advantages drilling costs should be less.

Discussion

T. M. Keiller, H. C. Le Vois (nonmember), **and E. L. Robinson** (nonmember; all of Gulf States Utilities Company, Beaumont, Tex.): In the Gulf Coast region, electricity has been extensively used for all the various power requirements of drilling, oil production, transportation, and refining.

The wildcat or exploration well is often quite a distance from sources of electrical energy, but we have numerous instances of temporary power lines built to locations that, in some cases, prove producing fields. Humble Oil and Refining Company has just built 7½ miles of 33-kv line across coastal marsh and running 1,600 feet out into the Gulf of Mexico. On this rig, wound-rotor motors are used, but the advantages of variable-voltage control could be realized by the use of an a-c motor generator set.

This system, more nearly approximating the steam rig in drilling characteristics, has in addition an advantage over straight a-c motors in the possible use of comparatively high-voltage synchronous motors with high power factor and attendant reduction in voltage regulation, often a factor in service to remote oil fields.

Should central-station service not be available on an economic basis, considering the possible duration of the requirements, it may be desirable to install a central power plant, distributing energy to several rigs, in which case the a-c motor generator set would be desirable.

From the point of view of the supplier of energy, the definite maximum demand, the absence of severe peaks, and the high power factor attainable, makes the a-c motor generator set with variable-voltage equipment a more desirable load than a straight a-c rig.

Another decided advantage that can be gained with the use of variable-voltage control with purchased electric power through the use of motor generator set is a saving in weight and space over Diesel electric. A large amount of activity along the Texas and Louisiana Gulf Coast is being carried on in salt marshes, open salt-water bays, and in the open Gulf, where the problem of adequate foundation is of prime consideration and great expense. The use of purchased electric power would permit lighter foundations, due to less equipment weight, therefore, greater foundation economy.

In addition, practically all fresh-water requirements would be eliminated. The cooling systems of engines used for generator drives require several barrels of make-up water per day. The hauling of fresh water is an expensive item and can be practically eliminated.

A safety feature in deep drilling is that variable-voltage control prohibits the placing of excessive strain on lines and derrick, thereby eliminating the possibility of pulling in the derrick.

Another advantage is that, if space and weight saving is desired but variable voltage is required on the draw works, a motor-generator set of sufficient capacity could be used for the draw-works motor only. The synchronous motor on the motor generator set could have an excitation range of sufficient capacity to correct power factor for a-c motors on the mud pumps. This would sacrifice the advantage of using variable-voltage control on the mud-pump motors, which provides against excessive duty on the pumps when washing a bridge-in well or stuck drill stem.

The driller would profit either in the purchase of power or generation in the central station from the reduction in demand, increase in power factor, and higher load factor possible. With more than one rig, diversity of peak demand would reduce the aggregate demand on the power source.

Once drilling crews become accustomed to the use of electric power rigs, they appreciate the ease of installation and increased speed of drilling operations. The variable-voltage system gives all these and the added advantages of the smooth high-torque variable-torque speed operation of the d-c motor.

P. L. Savage (nonmember; General Electric Company, Los Angeles, Calif.): I am sure we all are indebted to Mr. Lamberger for a very excellent paper on a subject which should be of great interest to the petroleum industry in particular and electrical engineers in general. In the writer's opinion, d-c equipment using variable-voltage control offers many advantages which are covered in considerable detail by Mr. Lamberger and should find more general use in the oil fields.

As suggested by Mr. Lamberger early in his paper, variable-voltage drilling is usually associated with internal-combustion engines. He also mentions that steam turbines and a-c motors have been suggested as prime movers but up to the present time, have not been used. A-c motors for generator drives, instead of engines, in particular, seem to offer a number of advantages which should be given serious consideration by the purchasers of oil-well-drilling equipment.

It must be admitted at the start that some locations where drilling operations are carried on, do not have a-c power available and in these locations, prime movers are to be favored. On the other hand, substantial percentage of oil-well drilling is done in locations where central-station power is available at reasonable cost. In such cases, the use of motor generator sets consisting of an a-c motor, of either the induction or synchronous type, driving the d-c generators, should be given careful scrutiny. Available central-station power lines are usually more than ample in capacity for the electric power requirements in drilling the deepest oil wells.

In this discussion, I would like to point out briefly the advantages of a-c motors when used for driving d-c generators.

It is generally admitted that the a-c motor has an advantage over the reciprocating engine on the basis of maintenance costs.

Ease of installation and portability are other factors which favor a-c motors to drive the generators, due to smaller size, lighter weight, and fewer auxiliaries.

Other considerations in favor of motor generator sets are:

1. No water for cooling is necessary.
2. There is no fuel problem.
3. The utility factor is practically 100 per cent.
4. More power per pound weight and per square foot of floor area occupied.
5. Lower first cost.

Many operating companies find it necessary to move drilling rigs from one field to another and in some cases, these new locations may not have a-c power available. This presents no serious problem since an a-c motor might be replaced with an internal-combustion engine for such locations. In the original design the d-c generators can be chosen so that the operating speeds are suitable for either motor or engine drive.

Mr. Lamberger has very clearly pointed out the advantages in the use of variable-voltage d-c power for drilling and has compared this operation with engines and mechanical transmissions.

In the past, where alternating current is available, it has been the practice of some operating companies to use a-c drilling equipment which consists of wound-rotor induction motors for furnishing the required power directly to the draw works and mud pumps.

It should be remembered that the a-c drilling motors obtain their speed variation by means of losses in the secondary or rotor circuit; therefore, a motor which has a full-load efficiency at full speed of approximately 90 per cent, drops immediately to something below 50 per cent at half speed, assuming that the torque remains constant. As the speed goes down, the efficiency drops in almost direct proportion. In addition to low efficiency at reduced speed, a considerable problem is encountered in maintenance, for the controller is required to carry heavy current. Also motor heating becomes a problem.

If d-c equipment were used with power supplied by a motor generator set, all of the advantages outlined by Mr. Lamberger would be available and the over-all efficiency would be expected to be much higher. Although we have interposed a motor generator set and must supply the losses to it, still the efficiency of the motor generator and d-c driving motor are maintained relatively high throughout the load range of the machine.

For instance, the efficiency of a motor generator set of suitable rating for oil-well drilling would be approximately 83 per cent which takes into account the combined efficiency of motor and generator. At half load, the efficiency has dropped to only approximately 80 per cent, which is very high as compared to the 50 per cent efficiency of a wound-rotor induction motor operating at a similar load.

Bearing out Mr. Lamberger's statement that electrical maintenance costs are low when variable-voltage d-c equipment is

used, it may be stated that there are two such engine-driven drilling rigs being operated by a major oil company in California at the present time. Although they were designed for drilling holes approximately 3,500 feet in depth, they have given an excellent account of themselves drilling much deeper holes and during the period since 1931, the expense of maintenance and repair parts for the electrical equipment has been negligible.

W. G. Taylor (General Electric Company, Schenectady, N. Y.): First let me congratulate Mr. Lamberger on his very fine paper which has been carefully prepared and presents the subject in a very interesting manner from a different angle from anything previously published on this subject. I feel sure that this paper will serve to clearly inform all engineers of the interesting and important phases of this application of electric drive with generator voltage control, even though they may not be familiar with the details of operation of oil-well rotary drilling rigs. Some points, which Mr. Lamberger may have touched on only lightly or not at all, have occurred to me as worth adding to round out his excellent presentation.

Essentially there are three major operations on a rotary drilling rig. The first is that of revolving the drill pipe and bit to drill the hole; the second, which occurs simultaneously with the first, is that of circulating mud down through the drill pipe and up outside of it to carry away the cuttings, plaster up the side of the hole to minimize caving, and provide a hydrostatic head to prevent blowouts where high gas pressures are encountered, this mud circulation being handled by reciprocating pumps; and the third operation is that of hoisting the drill pipe out of the hole to replace worn bits, and also putting the pipe back into the ground again, and likewise handling the casing which lines the hole after it is drilled. I mention this to bring out the point that the motor driving the rotary table to revolve the bit and the motor driving the mud pump must be able to operate with entirely independent speed characteristics and both run at the same time, and so a separate generator must be supplied for each because the speed regulation is by generator voltage control. Therefore, on a fully electrified rig, where all of these major operations are performed by motor drives, at least two generators must be used as Mr. Lamberger has stated.

A good many installations have been made where the pump is driven directly by the engines, which also drive a generator to supply power to the drilling motor, thus making what is known as a semielectric rig. As there is only one main motor in such a case and no mud-pump motors, only one generator is necessary.

In pointing out the advantages of a full-electric rig, Mr. Lamberger has mentioned that in some locations it is decidedly advantageous where suitable space near the well is at a premium, such as on steep hillsides. It might be added that another highly desirable location for this type of drive is in marine drilling, where the power equipment must be located on a barge, and where it is therefore not practical to use engines with direct mechanical drives to the rig, unless the piling used for supporting the derrick is greatly extended at considerable expense to provide a foundation for such a drive.

In explaining the relative characteristics of two-field and three-field d-c generators for this service, Mr. Lamberger has pointed out that in a given generator frame the three-field machine will have the advantage of higher free-hook speed resulting from the higher voltage obtained at light current load. High free-hook speed is considered essential in modern deep-well drilling because it shortens the time required to hoist the free hook from derrick floor to the top of the derrick when putting the pipe back into the hole length by length, and so reduces the nonproductive time when the rig is not making a hole. The speed obtainable is dependent not alone on the generator characteristics, but also on the gear and sprocket ratios of the drive from the motor to the hoisting drum, and on the amount of load on the motor which lifting the free hook involves. This load on a medium or heavy rig will amount to lifting a dead weight of from 10,000 to 15,000 pounds at a speed as high as 415 feet per minute in a 92-foot derrick. It is, however, hoisted on the upper part of the volt-ampere curve of the generator, and therefore the relation which the resulting hoisting speed of the free hook bears to the speed of hoisting loads of pipe depends upon the shape of that part of the generator curve. On a two-field generator this part of the volt-ampere curve is steeper than on a three-field design. Not so many years ago when the hoisting speeds for heavy loads were more moderate than they are now, the steeper curve of the two-field machine better fitted the conditions to be met, but since then speeds have been increased for heavy loads, making the flatter curve of the three-field machine better adapted for the purpose. The limit of speed at which the free hook can be hoisted is determined by the human element as represented by the ability of the drilling crew to handle the cycle of operations without a mistake and consequent loss of time which would offset any higher speed used.

Mr. Lamberger has described the difference in motor hoisting characteristics when running from generators in parallel as compared with generators in series. It may be noted, however, that normal hoisting of drill pipe with a properly applied d-c drive of either type is never carried on at the high-torque slow-speed end of the curves, shown in figures 3, 4, and 12, as the speed is too low to get the pipe out fast enough to suit any operator. A drive properly applied both as to horsepower capacity and gear and sprocket ratios should handle a heavy normal hoisting load on that portion of the horsepower-output curve of the motor or kilowatt-output curve of the generator which is at or near the peak output. Under such conditions it has been found, in the cases which have been checked, that the loss of one of two generators operating in parallel to supply the hoisting power will still leave enough torque available from the remaining generator to hoist the pipe at very low speed.

Another point to the advantage of the scheme of running the generators in parallel is that, on the modern four-speed draw works or hoist, only the three higher speeds are used for normal hoisting work, and the lowest speed is therefore available for increasing the rope pull at a given motor torque in an emergency.

There are many equipments in service, some of them designed for the generators to run in series and others designed for them to run in parallel for hoisting, and as far as I know all have given an excellent account of themselves and have met emergency conditions successfully.

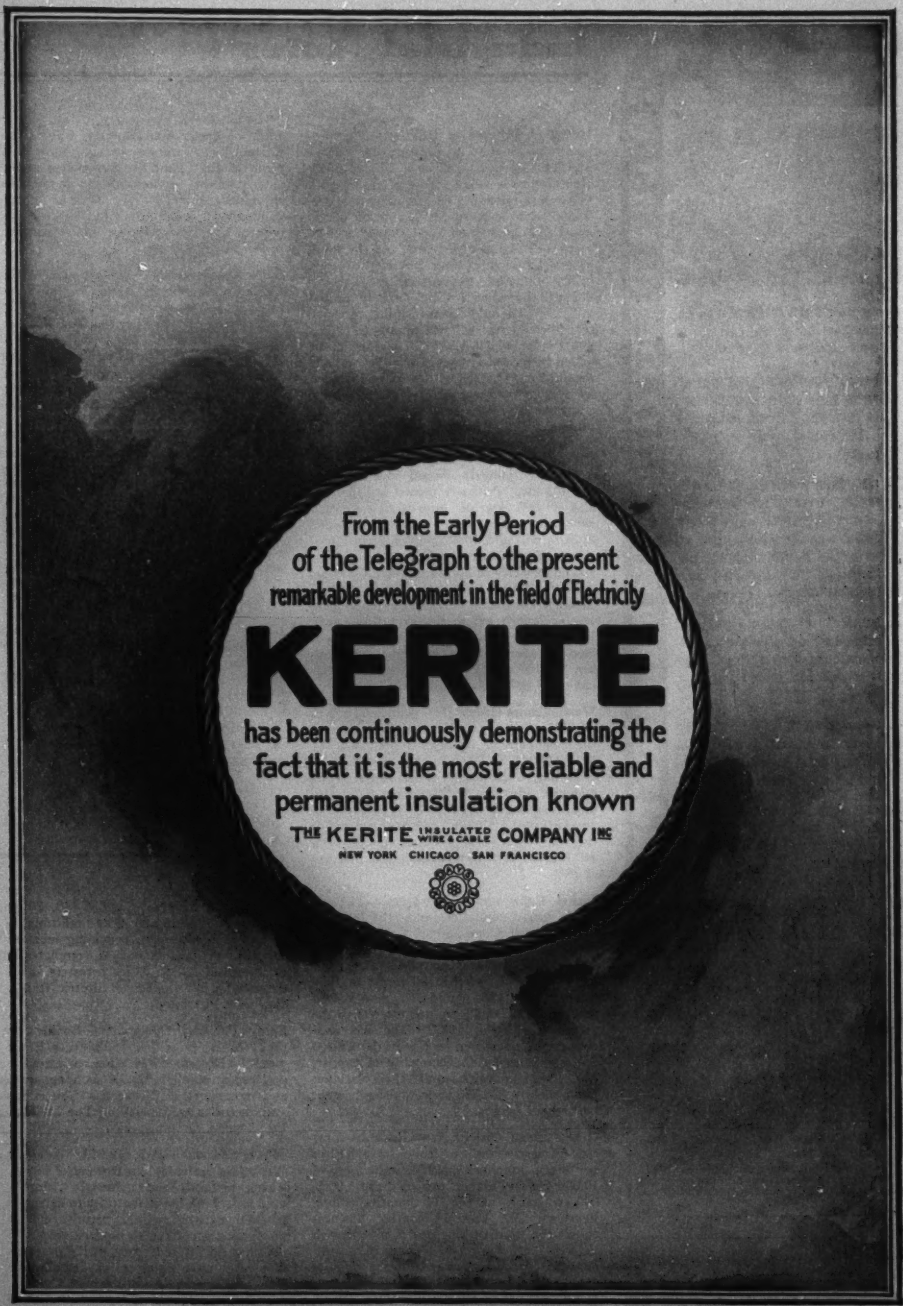
A. Naeter (Oklahoma Agricultural and Mechanical College, Stillwater): As an educator in a region where many electrical-engineering graduates enter various phases of electrical work in the oil industry, the writer feels that the author has made a valuable contribution to the available literature on variable-voltage rotary drilling rigs.

During the last few years the writer has been watching with interest a large drilling company in the southwest with regards to its drilling personnel. This particular company uses variable-voltage equipment driven by internal-combustion engines, and direct Diesel drive as well as conventional steam equipment. A few years ago this company hired an electrical-engineering graduate, with oil-field experience, and competent as electrician and machinist, to work as a motorman on a variable-voltage drilling rig. At first this employee faced considerable opposition from the practical men working on the rig. He soon "sold himself" to both employer and employees of the company to a degree that several additional electrical graduates were employed because the employer had become convinced that the electrical graduates had been able both to reduce maintenance costs and to speed up drilling operations. In time motormen became drillers, and then advanced to positions of greater responsibility. No practically trained employees were dropped, but electrical-engineering graduates were employed to fill vacancies, appearing through normal turnover, as well as new positions. Now the company no longer insists on oil-field background, and electrician and machinist skills, but trains its young engineers after employing them. This particular company is following an employment program that in time will place at least one graduate on each tour of every rig.

To an engineer in the educational field, it is encouraging to see young engineering graduates prove themselves in operating variable-voltage rotary drilling rigs at a time when many of the conventional fields of employment of the predepression days offer relatively few opportunities.

E. M. Gerry (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): In the second paragraph of Mr. Lamberger's paper he states that "*A-c motors* can be used to advantage [as prime movers] and have been proposed, but to our knowledge never actually used."

A well was drilled in Oklahoma several years ago, using d-c variable-voltage equipment, driven by a squirrel-cage induction motor. The final depth of the hole was over 10,000 feet; 7,500 feet of the total depth was drilled with special heavy 6¼-inch drill stem.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Industrial Notes

1940 Expenditures of Utilities.—The proposed construction expenditures by electric utilities this year will total $593,879,533, according to a recent report of the Federal Power Commission. Of this amount, $227,060,565 will be spent for generating plants and the remainder of $366,818,968 will be spent for other electric plant. Of the total, $490,434,261 represents privately owned utility outlay and the remainder, $103,445,272 will be expended by publicly owned utilities. The additional installed capacity scheduled during 1940 will amount to 1,877,844 kw, of which 1,332,635 kw are to be added by privately owned utilities and the remainder, 545,209 kw, are to be installed by publicly owned utilities. The scheduled additions of hydroelectric installations by private utilities total 57,000 kw, and by publicly owned utilities 234,175 kw; privately owned steam plant additions will total 1,264,085; publicly owned steam plants 270,372 kw. Privately owned utilities will add 11,550 kw of internal combustion generating equipment; publicly owned utilities will add 40,662 kw of such equipment. On January 1, 1940, the total installed capacity of all generating equipment was 40,317,924 kw. In addition to the capacity scheduled for completion during 1940, privately owned electric utilities have 1,653,375 kw of additional capacity scheduled for completion subsequent to December 31, 1940, and publicly owned utilities have 758,100 kw similarly scheduled.

Westinghouse Orders Up.—Incoming orders in 1939 reached the third highest level in the company's history, amounting to $214,239,044, an increase of 43% over 1938, according to the annual report of the Westinghouse Electric & Mfg. Co. Net sales billed totalled $175,071,363, 11% over the previous year. Unfilled orders at the end of the year were $70,821,960, compared with $40,188,150 at the end of 1938, an increase of 76%.

Nickel Consumption Increases.—The recently issued annual report of the International Nickel Company of Canada, Ltd., places the world consumption of nickel for 1939 at 256,000,000 pounds. The company's sales of nickel in all forms in 1939 were 210,194,135 pounds, a new record and nearly 2,500,000 pounds more than the previous high, in 1937. The increased consumption occurred largely in the United States. Sales by the company of copper, 324,850,921 pounds, and the platinum group metals, 240,778 ounces, also represent new record figures.

G-E Turbine Orders Near Record.—Turbine-generators ordered from General Electric since January 1, 1939, in ratings of 10,000 kw and higher, exceeded the 1,000,000-kw mark in the 14 months ending February 29. This 14-months' business equals the total turbine orders placed with the company during 1937 and 1938. An analysis of the orders indicates a definite trend to higher temperatures and pressures, and to the use of hydrogen cooling. Four-fifths of the million kilowatts will be produced by generators cooled by hydrogen instead of air. That the gas cooling is considered most economical for larger-sized machines is evidenced by the average capacity of such units, 43,700 kw. The average capacity of the air-cooled machines ordered is 28,900 kw.

Sales Appointments.—The Simplex Wire & Cable Co., Cambridge, Mass., has appointed G. F. Doughty as manager of its New York sales office. He has been continuously associated with that office for the past 17 years. . . . . Curtis C. Musgrove, previously representative of the Dallas territory, has been appointed representative for the whole state of Texas (with the exception of El Paso) and the states of Oklahoma and Louisiana, by the Pacific Electric Manufacturing Corp., San Francisco. Mr. Musgrove's offices are in the Insurance Building, Dallas. . . . . Cutler-Hammer, Inc., Milwaukee, has designated E. K. Anderson as manager of the company's branch office at Dallas in the Santa Fe Building. This office serves the states of Arkansas, Texas, Oklahoma and the southern part of New Mexico. . . . . D. S. Kerr has been appointed manager of the Atlanta office of the Allis-Chalmers Manufacturing Co., Milwaukee. He has been employed by the company since 1922 and was previously manager of the Chattanooga office. Both the latter and the Knoxville office will be under his jurisdiction. . . . . The Standard Transformer Co., Warren, Ohio, has appointed H. H. Knowles, Watts Bldg., Birmingham, as sales representative for the state of Alabama.

Trade Literature

Lightning Arresters.—Cat. 38-140, 20 pp. Describes 3-, 6-, and 9-kv lightning arresters of new design, providing increased surge-carrying capacity. A complete line of improved 12- to 73-kv arresters is also described. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Spray Painting Equipment.—Booklet, 32 pp., "A, B, C of Spray Painting Equipment." Describes operation, maintenance and repair of all forms of such apparatus and accessories. Numerous illustrations and diagrams are included. The DeVilbiss Co., Toledo, O.

Wiring Manual.—Pub. 51-919, "Adequate Wiring for Industry", a manual of modern wiring methods and materials. May be used as a check list in factories to determine whether existing wiring permits efficient production according to modern standards. Outlines the latest factory wiring practices; illustrates case histories of installations. General Electric Co., Bridgeport, Conn.

(Continued on page 8)

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Trade Literature

(Continued from p. 6)

Recording Tachometers.—Bulletin 542. Describes recording and indicating, round-chart and strip-chart, potentiometer type tachometers. As many as eight records can be made on the 12-inch chart of the strip-chart tachometer. The Bristol Co., Waterbury, Conn.

Capacitors.—Bulletin GEA-3225, 16 pp. Describes Pyranol capacitors, recommended applications, and examples of application calculations. Includes power factor improvement table, definitions of power factor, power factor improvement and adjustment rates. General Electric Co., Schenectady.

Gears and Reducers.—Catalog 110, 256 pp. Lists stock gears and reducers of all types, and other transmission equipment. Comprehensive tables covering types, sizes, engineering data, and prices are included. Brad Foote Gear Works, Cicero, Ill.

Voltage Regulator.—Bulletin B-6056, 28 pp. Describes three-phase, AFR $^{5}/_{8}$ per cent step feeder voltage regulators for regulating voltage under load on feeders and busses from 1,200 to 66,000 volts in ratings up to 750 kva. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Switch Insulators.—Bulletin. Describes switch and bus insulators. Selection of required types is simplified by the arrangement of pertinent data. Methods of judging insulators, advantages of pin-caps and station posts, are outlined and useful handbook data is included. Ohio Brass Co., Mansfield, Ohio.

Resistance Standards.—Bulletin 146-1. Describes resistance standards, decade boxes and special parts for electrical measurement. The data included enables the engineer to quickly select such instruments with suitable characteristics for specific applications, i. e., for testing, instruction, or research. Shallcross Mfg. Co., Collingdale, Pa.

Portable Instruments.—Catalog GEA-1784B, 28 pp. Describes various types of a-c and d-c, pocket-size, portable instruments, including voltmeters, ammeters, milliammeters, etc. Comprehensive tables include all essential data, on all ranges, with prices. Scale markings of all types are illustrated. General Electric Co., Schenectady.

Insulating Compound.—Bulletin, 12 pp. Describes "Insolozite", a plastic filling compound, which is insoluble in oils or compounds used in the process of impregnating paper-insulated, lead-covered cable. It is recommended for filling such cable joints operating at any voltage where a plastic filling compound is indicated. It may also be used for filling terminals, junction boxes, transformer bushings and other similar applications. General Cable Corp., 420 Lexington Ave., New York City.

Telephone Cables.—Catalog, 32 pp. Describes lead covered, jute protected, wire and tape armored, and switchboard cable, including the recently developed 2,121 pair unit, which adds 606 conductors to the largest previous cable. Illustrated with photographs of historical, manufacturing, and installation operations, with diagrams showing interesting constructional features, and contains much tabular and factual data. Western Electric Co., 195 Broadway, New York City.

Balancing Machines.—Bulletin 1079, 32 pp. Describes a line of static and dynamic balancing machines for locating and measuring unbalance in rotating parts. Available in small and large sizes, such machines will measure and locate either pure static or pure dynamic unbalance or both. Detailed explanations of the effects of unbalance in rotating parts are included, as well as diagrams and descriptions of the underlying principles of the methods for correction. Gisholt Machine Co., Madison, Wis.

Bearings.—1940 Catalog. Lists and describes over 800 sizes of plain bearings and more than 350 of bronze bars. Many new numbers have been added to the electric motor bearing section and each bearing is illustrated. Graphited bronze and ledaloyl self-lubricating bearings are included. Johnson Bronze Co., New Castle, Pa.

Mercury Vapor Transformers.—Bulletin, 8 pp. Describes mercury vapor transformers for indoor and outdoor applications; outlines the characteristics of mercury vapor lighting and the various types of lighting systems for specific and general applications. Of reference value in determining the proper lighting systems, as it includes calculating tables and charts, which when used according to basic rules established, predetermines the necessary amount of light for various applications. The Acme Electric & Mfg. Co., Cuba, N. Y.

Potentiometers.—Catalog E-50B (3), "Type K potentiometers and Accessories", 24 pp. Describes and lists types K-1 and K-2 potentiometers. The latter has three ranges, convenient controls, strong coverings for all electric conducting parts and it is standardizable without moving range switch or changing potentiometric setting. Galvanometers and other accessories for use with these instruments are also described. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

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New Products

Rectifiers Solve Change-Over Problems.—A line of rectifiers for supplying direct current power from a-c source, has been developed by H. J. McCreary, consulting engineer, 105 W. Adams St., Chicago. The most recent addition to this line is illustrated. It is a 3-phase, bridge-type rectifier, which gives 6-phase performance.

It is designed to deliver 45 amperes continuously at 115 volts d-c, from a 122-volt, 60-cycle, 3-phase a-c supply. The ripple voltage which is superimposed over the d-c voltage is less than 3 volts when the unit is fully loaded and delivering 45 amperes. No power transformers are used in this rectifier, aside from a filament transformer which consumes less than 300 watts regardless of load. Protective devices are provided which include reactors and fuses. This unit has been employed with three, standard, single-phase transformers connected delta, delta to supply 45 amperes at 115 volts d-c from 550 volts, 60 cycles, 3-phase a-c. According to the designer, the numerous changeover rectifiers installed in the Chicago area have given very satisfactory performance over the past two years.

Automatic Reset Timers.—A new series of automatic reset timers and time delay relays has been introduced by the Paragon Electric Co., 37 W. Van Buren St., Chicago. The following types of uses suggest the wide adaptability of these instruments (1) To close and then reopen a circuit (2) To open and then reclose a circuit (3) To make a momentary contact (4) To repeat a preset schedule of momentary contacts or timed "on" and "off" operations (5) To reset instantaneously after a power failure. These timers are furnished with eight terminals. A positive mechanical lock, magnetically operated, eliminates all friction and magnetic clutches.

Distribution Transformer.—The recently introduced round tank, distribution transformer of the Kuhlman Electric Co., Bay City, Mich., embodies many new features. It employs newly designed pocket type bushings on all units from $1\frac{1}{2}$- to 50-kva, up to and including 13,200 volts. The pockets for both primary and secondary bushings are pressed directly into the tank body. The metallic parts of the bushing are entirely surrounded with porcelain, and by a turn of a porcelain knob the clamping mechanism is opened or closed, freeing or securely gripping the line connection. The terminal support does not depend exclusively upon the point of contact, but is further supported by the main body of the bushing, overcoming the tendency to wire breakage. In laboratory tests over 2,000,000 vibrations were applied without loosening or breaking the wire. Cover type bushings

can also be furnished, if desired. The entire tank body is formed from corrosion-resistant, copper-bearing steel. The top edge is rolled out and forms a perfect gasket seat; the bottom is seam-welded and rolled to provide an extremely strong reinforced base. The cover clamps are forged and machined from bronze; no part need be removed in taking off the cover. Kuhlman "Mogul-Type" lifting lugs greatly facilitate handling. The company's patented, bent-iron core and coil is standard on all distribution transformers from $1\frac{1}{2}$ to and including 25 kva, 2400 through 7620 volts.

Diminutive Ball Bearings.—The Norma-Hoffmann Bearings Corp., Stamford, Conn., which pioneered the manufacture of small precision ball bearings down to $\frac{1}{8}$-inch in bore, announces that its small sizes, which have heretofore been available in the "full" (retainerless) type, can now be obtained as standard with retainers (or ball cages). The dimensions of these diminutive ball bearings are as follows:

Bearing No.	Bore	O. Dia.	Width
N-463-R	$\frac{1}{8}$"	$\frac{1}{4}$"	$\frac{1}{8}$"
4666-R	$\frac{1}{10}$"	$\frac{1}{4}$"	$\frac{1}{8}$"
XA-134-R	$\frac{1}{4}$"	$\frac{1}{8}$"	.196"
XA-134-R-P	$\frac{1}{4}$"	$\frac{1}{8}$"	.196"
XA-134-R-PP	$\frac{1}{4}$"	$\frac{1}{8}$"	.196"

Tower Ground Wire Bracket.—To provide a suitable ground wire bracket for mounting on steel structures, the Ohio Brass Co., Mansfield, has developed a device with a flat supporting piece, drilled with four holes to allow bolting to a steel tower, a fabricated steel pole or a bayonet extension. Using a clamp mounted on top of the device this bracket, known as the Clamptop, permits an increase of spacing between ground wire and

conductors of 6 inches or more over any other designs, assuming the same bolt holes are used. The bracket proper has two pintles on which the clamp body rests. Two carriage bolts hold the clamp to the bracket and secure the keeper piece over the ground wire. Since the clamp pivots 15 degrees above or below the neutral position, ample clearance for rocking action is provided. This flexibility, similar to that afforded by a suspension clamp, tends to prevent damage to the ground wire at the point of attachment. Having a reversible keeper piece, the clamp holds any wire from $\frac{1}{4}$ to $\frac{9}{16}$ inch. A design also is available for mounting on wood poles.

Vibration-Isolator.—A new, easily installed vibration isolator, designed to economically control machine vibration and reduce the resulting noise, recently announced by Johns-Manville, 22 East 42nd St., New York City, is known as the J-M controlled spring isolator, and was developed for use on the bases of motors, generators, pumps, ventilating fans and similar equipment. The working parts of the unit consist of a coil spring and a rubber load pad, which support the equipment and isolate vibration, and an adjustable rubber snubber inside the base, which controls excessive motion. The isolator was built to take care of horizontal and torsional as well as vertical vibration, and tests by the company's research laboratories, where the unit was developed, indicate it to be particularly efficient for the low frequency vibrations resulting from slow speeds and from many operatons involving reciprocal action. The load pad is designed to overcome any high frequency vibrations. Both light and heavy duty types are available.

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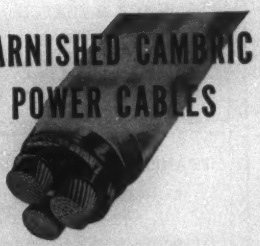

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B.S.E.E., 1939; 22, single; some exper as automobile mechanic's asst; draftg exper, mun research. Desires pos as jr engr with a mfg or util co. E-617.

E.E., SB and Sm M.I.T., 1924; 41, married; 6 yrs tel; 8 yrs des and production engg, mfg; 19 mos state public works; elec des USHA project. Professional license, Conn. E-618.

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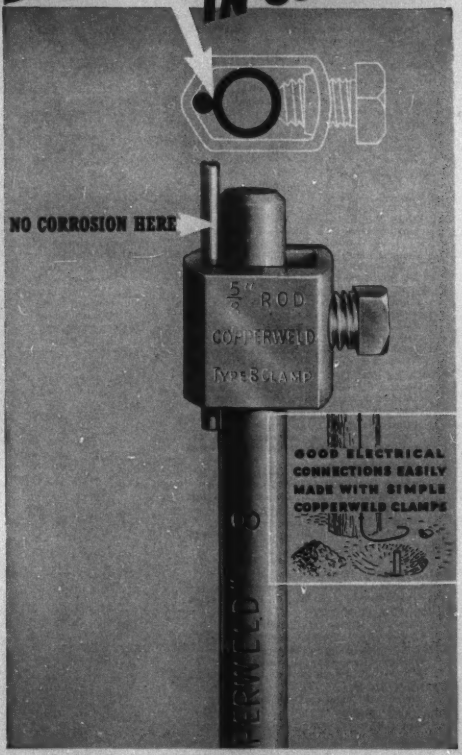

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SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Mineralac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., Bethlehem, Pa.
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES, GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Kuhlman Electric Co., Bay City, Mich.
Sola Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

TRANSPARENT PRINTS
Oxalid Corp., Johnson City, N. Y.

TURBINES and TURBINE GENERATORS
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

WELDERS, ARC
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

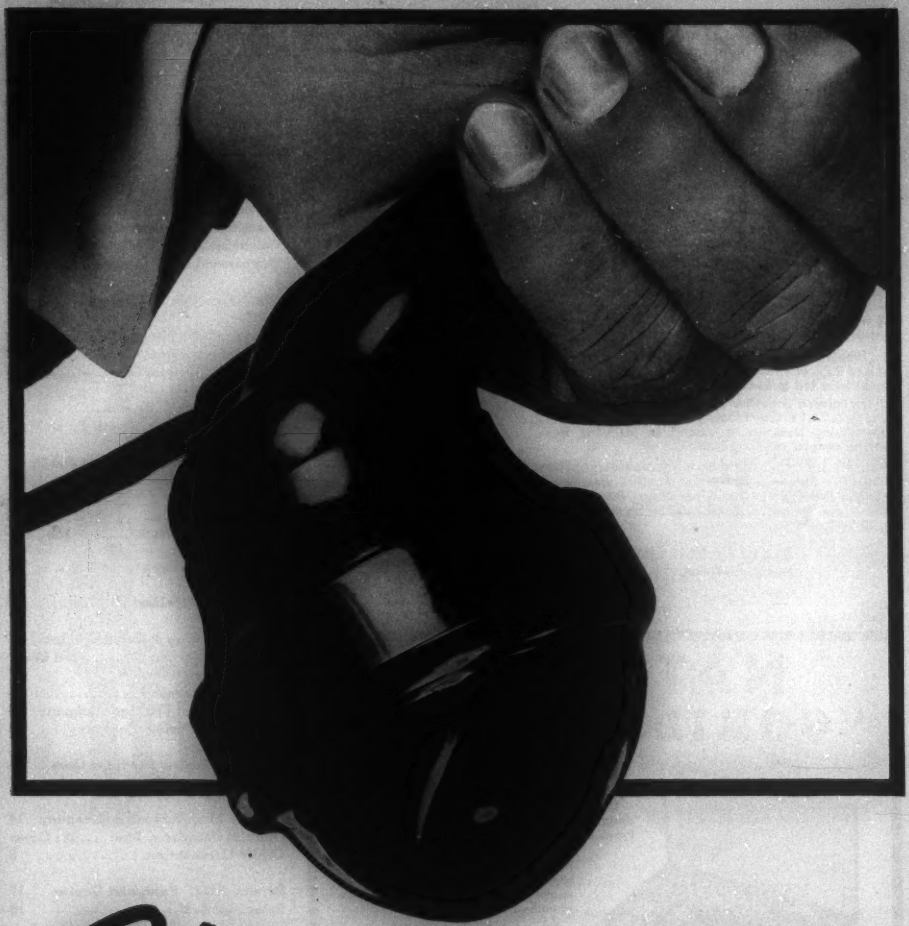
WELDING WIRE
American Steel & Wire Co., Cleveland, O.
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

WIRES AND CABLES
Aluminum
Aluminum Co. of America, Pittsburgh
Armored Cable
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Asbestos Covered
American Steel & Wire Co., Cleveland, O.
General Cable Corp., New York
General Electric Co., Bridgeport, Conn.
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Bare Copper
American Steel & Wire Co., Cleveland, O.
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
National Elec. Products Corp., Pittsburgh
Roebling's Sons Co., John A., Trenton, N. J.
Bronze
Copperweld Steel Co., Glassport, Pa.
Copper Covered Steel
American Steel & Wire Co., Cleveland, O.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
Flexible Cord
American Steel & Wire Co., Cleveland, O.
Belden Mfg. Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Heavy Duty Cord
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
American Steel & Wire Co., Cleveland, O.
Belden Mfg. Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Rubber Insulated
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Tree Wire
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Weatherproof
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
National Elec. Products Corp., Pittsburgh
Okonite Company, The Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

WHITEPRINT PROCESS EQUIPMENT
Oxalid Corp., Johnson City, N. Y.

WHITEPRINT PAPERS, CLOTHS, FOIL
Oxalid Corp., Johnson City, N. Y.

X-RAY UNITS, INDUSTRIAL
General Electric X-ray Corp., Chicago, Ill.



Big enough for the job

We live in a big country and it takes a big telephone company to give good service to millions of people. The Bell System is doing its part in providing for the nation's telephone needs, whatever they may be.

But the Bell System aims to be big in more ways than mere size. It aims to be big in the conduct of its business, in its relations with employees and its plans for the future. All of this helps to give the nation quick, dependable, courteous telephone service at low cost.

BELL TELEPHONE SYSTEM

800,000 Guy Hook Installations—Why?

Why have Electric Light and Power Companies, constituting over half the operating capacity of the U. S. and Canada, placed this M. I. F. line of Through-bolt Guy Hooks on their approved lists? The result has been 800,000 installations in a little over four years, and this is why—or so we are told:

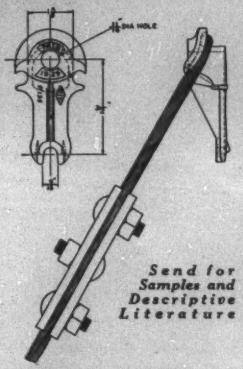
1. Simplification of Guying Specifications results from the use of M. I. F. Through-bolt Guy Hooks as they are used with stock through-bolts and lags.

2. Economical construction results as the M. I. F. Guy Hook is cheaper than other acceptable through-bolt guying devices developing equal performance under test. Accessory Curved Ribbed Washers, Eye Nuts, Bolt Eyes, and High-strength Thimbleless Eye Anchor Rods are all competitively priced, or better. The durability of these galvanized malleable castings is beyond question.

3. Safe construction results from using M. I. F. Guy Hooks. As the guy loop is made up on the ground and then carried up the pole and placed over the Guy Hook retaining ear, protection from contacting live wires is more readily assured. There are no records of failures in service.

4. Proper through-bolt guying leads to no regrets. At least 95% of all sales of 100 or more M. I. F. Guy Hooks have led to consistent repeat orders.

To Transmission and Distribution Engineers, not now using these M. I. F. Guy Hooks and Accessory Through-bolt Guying Devices, we extend an invitation to write for samples *without obligation.*



Send for Samples and Descriptive Literature

Misc. M. I. F. Pole Hardware Specialties:—*Williams Pole Mounts—Pole Stubbing Clamps—Aerial Cable Messenger Clamps and Insulated Hangers—Malleable Secondary Racks and Clevises—Tubular Pole Fittings—Transformer Hanger Plates for Through-bolt Mounting—Malleable Crossarm Gains—Screw Anchors—Sidewalk Guy Fixtures and Alley Arm Braces—Crossarm Braces—Guy Strand Payout Reels—Through-bolts, etc.*

MALLEABLE IRON FITTINGS COMPANY

Pole Hardware Dept. [Factory and New England Sales Offices] Branford, Connecticut

New York Sales Office: Thirty Church Street

Canadian Mfg. Distributor: LINE & CABLE ACCESSORIES, Ltd., Toronto

NATIONAL "GORILLA GRIPS"

For Flexibility . . .

Gorilla Grip Pressure Connectors have been designed for flexibility (one nut will fit many types of bodies) without sacrificing precision. It takes just a few seconds to select the type of bodies required and assembled with nut which is clearly marked with conductor size and easily identified.

This set is for the large jobs with a strong leather handle for carrying. It contains Lug Bodies, Straight Connector Bodies, Parallel and 90° Cable Tap, plus Terminal Units and Reducing Sleeves for conductor sizes 500 MCM to 2 Stranded inclusive.

Gorilla Grip Set 500 MCM to 2 Stranded.

125 Combinations are obtainable in this set. No special tools required.

National Electric PRODUCTS CORPORATION

Pittsburgh, Pennsylvania

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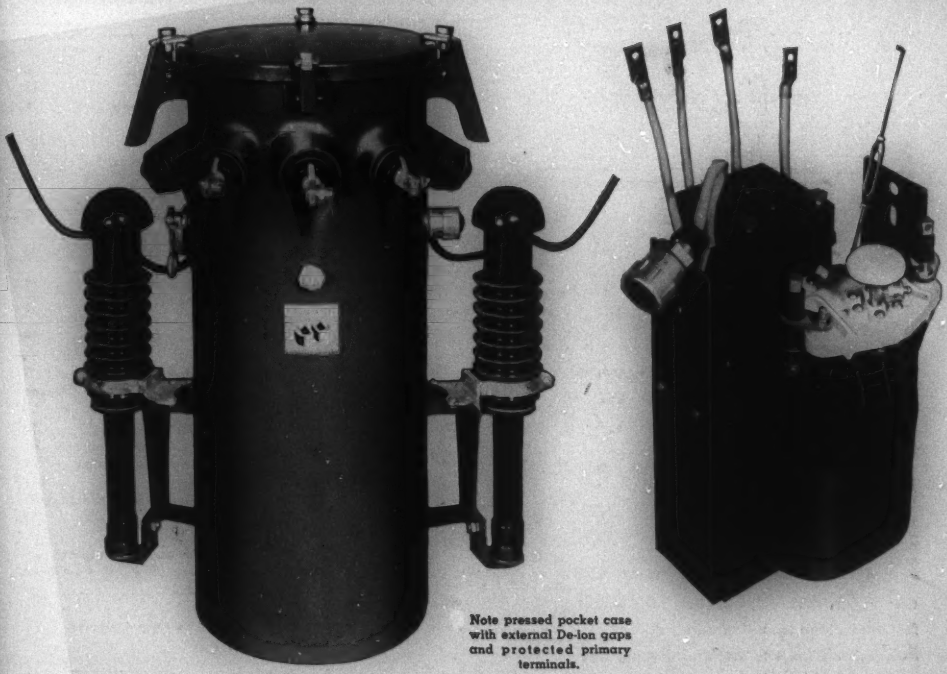
Kuhlman CSP TRANSFORMER

WITH KUHLMAN BENT IRON CORE . .



Note pressed pocket case with external De-ion gaps and protected primary terminals.

COMBINED IN ONE EFFICIENT, SELF-PROTECTING UNIT

In the Kuhlman CSP Transformer the time-tested and proven Kuhlman B.I. Core is combined with accessories that result in a self-contained, completely self-protecting unit.

The Kuhlman B.I. Core is fluxed with the grain of the core material and thus utilizes to the fullest extent the most desirable characteristics inherent in improved transformer materials. Permeability is higher, hysteresis is lower.

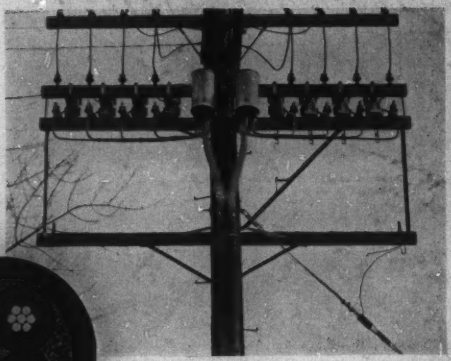
When installed on the pole, and connected directly to the line without separate cutouts or lightning arresters, the Kuhlman CSP Transformer provides protection against dangerous over-voltages from lightning and other causes by use of De-ion gaps and 3-point, co-ordinated insulation. A circuit breaker protects it against secondary short-circuits and overloads. It allows short emergency overloads within safe temperature limits. It provides protection against line outages by means of internal fusible links. It automatically signals when transformer is operating above normal temperatures.

For complete facts about the Kuhlman CSP Transformer, write for bulletin No. 340.

For facts about the Kuhlman standard distribution transformer write for bulletin No. 40.

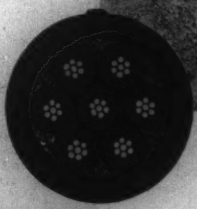
KUHLMAN ☆ ELECTRIC COMPANY

CABLE PROTECTION
in its simplest form



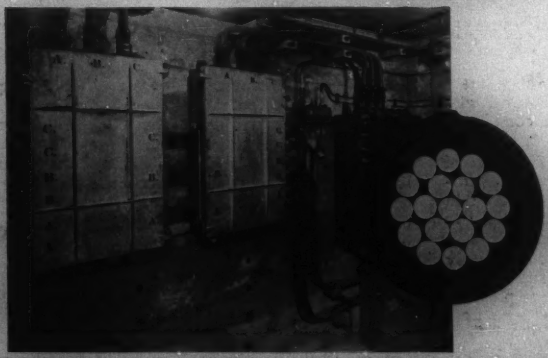
Okosheath-jacketed high-voltage feeder cable with Okolite-insulated conductors. In this installation pole-riser connections were made in a terminating joint.

Against moisture, corrosion and mechanical damage, Okosheath makes the ideal non-metallic cable covering. On single conductor cables one thickness of Okosheath rubber provides protection all the way in to the conductor and insulation all the way out. On multiple conductor cables an Okosheath rubber jacket gives lasting protection and, in addition, provides extra insulating value.



Okosheath multi-conductor signal cables buried directly in the ground. The tough Okosheath jacket protects against soil corrosion and mechanical damage.

Okosheath-insulated single conductor cables for low voltage secondaries in a duct installation. Insulation and mechanical protection are combined in a single covering.



For complete information
Write for Bulletin **OK–2013**

THE OKONITE COMPANY

Founded 1878

EXECUTIVE OFFICE: PASSAIC, NEW JERSEY

HAZARD INSULATED WIRE WORKS DIVISION

THE OKONITE-CALLENDER CABLE CO., INC.

SALES OFFICES IN PRINCIPAL CITIES